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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AN ADDITIONAL INVESTIGATION OF THE HIGH-SPEED LATERAL-CONTROL CHARACTERISTICS OF SPOILERS

By Edmund V. Laitone and James L. Summers

Ames Aeronautical Laboratory
Moffett Field, California

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NACA ACR No. 5D28

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE CONFIDENTIAL REPORT

AN ADDITIONAL INVESTIGATION OF THE HIGH-SPEED LATERAL-CONTROL CHARACTERISTICS OF SPOILERS

By Edmund V. Laitone and James L. Summers

SUMMARY

The charactoristics of partial-span spoilers located at 0.75 of the chord on an NACA 66-series tapered wing, particularly at high speeds, were investigated. The effect of small spoiler projections was found to increase with an increase in speed until the critical Mach number was exceeded. The data indicate that a spoiler having a small projection in front of an aileron provides a considerable increase in control, especially at high speeds. A spoiler projecting from the upper wing surface produced no adverse effects on the aileron. However, spoilers projecting from both upper and lower surfaces, which were investigated as a possible control for tailless airplanes, produced serious buffeting and reversal of the hinge moments of the aileron.

INTRODUCTION

Previous tests (reference 1) showed that a spoiler in front of a conventional aileron will increase the rolling moment as well as decrease the stick force. At high speeds, even a small projection of the spoiler produced a large increase in the lateral-control effectiveness. In reference 1 it was also suggested that a spoiler could be used in front of the elevator of a conventional tail plane for additional control at high speeds. The possibility of using spoilers for the directional or longitudinal control of tailless airplanes was also noted.

The present investigation was made to provide further information on the effect of a spoiler, especially at high speeds. Smaller and larger spoilers were tested over an extended speed range. In addition, spoilers projecting simultaneously on the upper and lower surfaces were investigated.

APPARATUS AND METHOD

The model tested was a semispan low-drag (NACA 66-series) tapered wing (fig. 1(a)). It was mounted in the 16-foot wind tunnel of the Ames Aeronautical Laboratory, as shown in figure 2. This model was one used for the tests reported in reference 1 except that the aileron nose balance was 0.45 of the aileron chord (fig. 1(b)) and most of the spoiler data were obtained with the aileron unsealed.

The spoilers extended along the 0.75-chord line of the wing surfaces and projected normal to the surfaces directly in front of the aileron (fig. 1(a)). The span was the same as that of the aileron, 0.41 of the wing semispan, and the inboard ends of both the spoiler and aileron were at 0.5 of the wing semispan. The spoiler projections ranged from 0.005 to 0.08 of the local wing chord (c). All the spoilers had smooth plane surfaces except the 0.04c slotted spoiler which had 1/4-inch-wide slots spaced 1/2 inch center to center (fig. 1(b)).

The spoiler tests were made with the wing surfaces smooth and with the aileron unsealed. Since the gap at the leading edge of the aileron balance was large relative to the cover plate gap (fig. 1(b)), the unsealed aileron should have the characteristics of a plain unbalanced aileron. In order to determine the effect of a complete aileron seal, however, additional tests were made with the 0.02c spoiler wherein the nose and both ends of the aileron balance were sealed with thin sheet rubber. The effect of roughness on the action of the 0.02c spoiler was investigated by applying a 3/8-inch-wide strip of No. 60 carborundum particles at the 0.10-wing-chord line along the entire span of the upper and lower surfaces.

The relative amount of aileron buffeting was determined in each case by observing the hinge-moment indicator. As a check on this observation, several tests were made restraining the aileron by hand only.

The tests were made through a Mach number range of 0.188 to 0.75 with a corresponding Reynolds number range of 5,000,000 to 13,800,000 based on the mean aerodynamic chord of 3.84 feet. The relation between the Reynolds number and the Mach number for these tests is shown in figure 3.

SYMBOLS

The symbols used in the presentation of the results are defined as follows:

M	Mach number based on tunnel-empty calibration
q	dynamic pressure of the air stream based on the tunnel-empty calibration $\left(\frac{1}{2}\rho V^2\right)$
C_l	rolling-moment coefficient (L'/qbS)
C_n	yawing-moment coefficient (N'/qbS)
C_m	pitching-moment coefficient $\left(\frac{M'}{qS(M.A.C.)}\right)$
C_D	drag coefficient (D/qS)
C_L	lift coefficient (L/qS)
C_h	aileron hinge-moment coefficient $(H/qb_a\overline{c_a}^2)$
c	wing chord, feet
c_a	aileron chord measured along airfoil chord line from hinge axis of aileron to trailing edge, feet
$\overline{c_a}$	root-mean-square chord of the aileron, feet
b	twice span of the semispan model, feet
b_a	aileron span, feet
S	twice area of semispan model, square feet
L'	uncorrected rolling moment, due to aileron and/or spoiler, about wind axis in plane of symmetry (at the wind-tunnel wall), foot-pounds
N'	uncorrected yawing moment, due to aileron and/or spoiler, about wind axis in plane of symmetry (at the wind-tunnel wall), foot-pounds
M'	twice uncorrected pitching moment (about $\frac{1}{4}$c of M.A.C.) of semispan model and strut, foot-pounds

D twice uncorrected drag of semispan model and strut, pounds

L twice uncorrected lift of semispan model and strut, pounds

H aileron moment about hinge axis, foot-pounds

α uncorrected angle of attack, degrees

δ aileron deflection relative to wing, degrees (deflection positive when trailing edge is down)

RESULTS AND DISCUSSION

The data presented (figs. 4 to 24 are based on the complete wing dimensions given in figure 1(a)). None of the data are corrected for strut or tunnel-wall effects. All the data except those presented in figure 16 are based on the assumption that only the left aileron was deflected and the spoiler when present, was on the left wing only. The data presented in figure 16 are based on the assumption that the spoilers are simultaneously projected on the upper surfaces of both wing tips. The pitching-moment coefficient is based on the mean aerodynamic chord (3.84 ft) and on the pitching moment about the one-quarter-chord point of the mean aerodynamic chord.

For the angle-of-attack range of 0° to 4° and with small spoiler projections the critical Mach number varied from 0.68 to 0.83. Figures 4 to 8 show that, in general, the effects of small spoiler projections became a maximum at a Mach number slightly greater than the critical Mach number, and then decreased rapidly as the Mach number was further increased. Therefore, it may be necessary to use larger spoiler projections at Mach numbers greater than the critical, since the large projections are relatively more effective at a Mach number of 0.75. However, figures 9, 11, and 13 show that spoiler projections less than 0.02c are proportionally more effective than larger ones in affecting the rolling-moment, pitching-moment, and lift coefficients, for Mach numbers less than 0.75. Figures 14 and 16(a) indicate that the spoiler could be used for additional lateral control during landing since it is effective even at the angle of stall. Figure 16 shows that the effectiveness of the spoiler on the upper surface decreased with angle of attack, and therefore the lift-

curve slope was increased by the spoiler. Figures 17 and 19 show how much the spoiler increased the rolling moment and at the same time decreased the aileron hinge moment.

Figure 19 shows the effect on the aileron hinge moment of 0.01c spoilers projected on the upper and lower surfaces simultaneously. The reversal in the aileron hinge moment became excessive for larger spoiler projections. Also, the use of both upper-surface and lower-surface spoilers in front of the ailerons produced buffeting which became violent as the Mach number increased above 0.5. However, the 0.02c spoiler on the upper surface alone produced no more shaking of the aileron than was present with no spoiler. Consequently, in front of a hinged flap a spoiler projecting from only one surface at a time should be used. Spoilers on both surfaces may provide control for a tailless airplane. However, it does not seem possible to sufficiently isolate the desired effect. For example, figures 6 and 8 show that an increase in lift would be accompanied by a negative pitching moment while a positive pitching moment would be accompanied by a decrease in lift, thereby making a pull-out from a dive very difficult.

Figures 4, 6, and 8 show that the slots in the 0.04c spoiler decreased its effect on the rolling moment, pitching moment, and lift so that it became approximately equivalent to a 0.02c unslotted spoiler. Figure 19 shows that the slots reduced the effect of the 0.04c spoiler in decreasing the aileron hinge moment to that of a 0.005c unslotted spoiler. Also, the slots produced a slight buffeting of the aileron.

Figures 20 and 21 show that the complete aileron seal had only a slight effect on the change in rolling moment produced by the 0.02c spoiler. The effect of the seal on the hinge moment, however, seems to be beneficial at the higher speeds.

Figures 22 and 23 show that, in general, the roughness at 0.10c decreases the effect of the 0.02c spoiler as would be expected. However, the change is surprisingly small in view of the rearward location (0.75c) of the spoiler.

The data show that for a Mach number range of 0.3 to 0.7, wherein the Reynolds number varied from 7,700,000 to 13,800,000, the 0.05 spoiler was at least half as effective as a 0.01c spoiler. Figure 19(b) shows that the hinge moment of the aileron varied uniformly with aileron deflection

when the spoiler projection was 0.05c. The effectiveness of the small spoiler projections in those tests may be attributed to the large Reynolds numbers and low airstream turbulence. Previous tests (reference 2) of conventional wing sections at a Mach number of 0.05 and a Reynolds number of only 2,000,000 with a relatively high air-stream turbulence indicated that spoiler projections of 0.01c or less have no effect on the rolling moment. Figure 24 shows that the rolling moment due to the 0.005c spoiler decreased when the Reynolds number became less than 7,700,000. Figures 14 and 15 show that at a Reynolds number of 5,000,000 the 0.05c spoiler produced very little rolling moment, but the yawing moment it produced was still approximately half that for a 0.10c spoiler. Under flight conditions where the air-stream turbulence is low, at least for wing tips and tail surfaces out of the slipstream, the effects of the small spoiler projection should be similar to those presented in this report if the surfaces are fairly smooth.

It should be noted that the Reynolds number and Mach number were varied simultaneously, and, therefore, the effects of independently varying the Reynolds number or the Mach number cannot be precisely determined from these data.

RECOMMENDATIONS

Spoilers alone can provide sufficient lateral control so that they could replace conventional ailerons. However, a time-motion study would have to be made in order to determine the suitability of this type of spoiler for lateral control.

Spoilers projecting from both upper and lower surfaces may provide control for tailless airplanes, but a time-motion study and a further investigation of the buffeting of this arrangement would be necessary.

Perhaps the best possibility lies in using a small spoiler projection in front of a hinged flap. The time lag and buffeting of this combination should be negligible. It would probably be best to select the size of the hinged flap so that only spoiler projections less than 0.02c would be required since the smaller spoiler projections are proportionately more effective, at least for speeds not exceeding the critical Mach number. However, an arrangement should be

provided so that larger spoiler projections could be used for speeds greater than the critical Mach number.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

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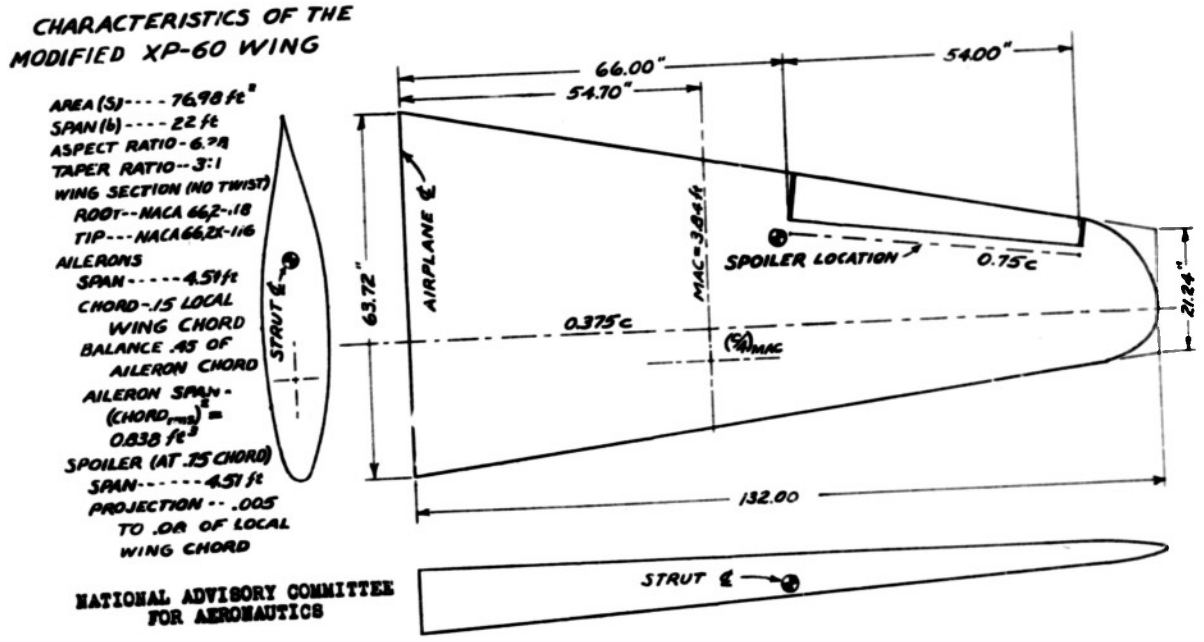
1. Laitone, Edmund V.: An Investigation of the High-Speed Lateral-Control Characteristics of a Spoiler. NACA ACR No. 4C23, 1944.

2. Wenzinger, Carl J., and Rogallo, Francis M.: Wind-Tunnel Investigation of Spoiler Deflector, and Slot Lateral-Control Devices on Wings with Full-Span Split and Slotted Flaps. NACA Rep. No. 706, 1941.

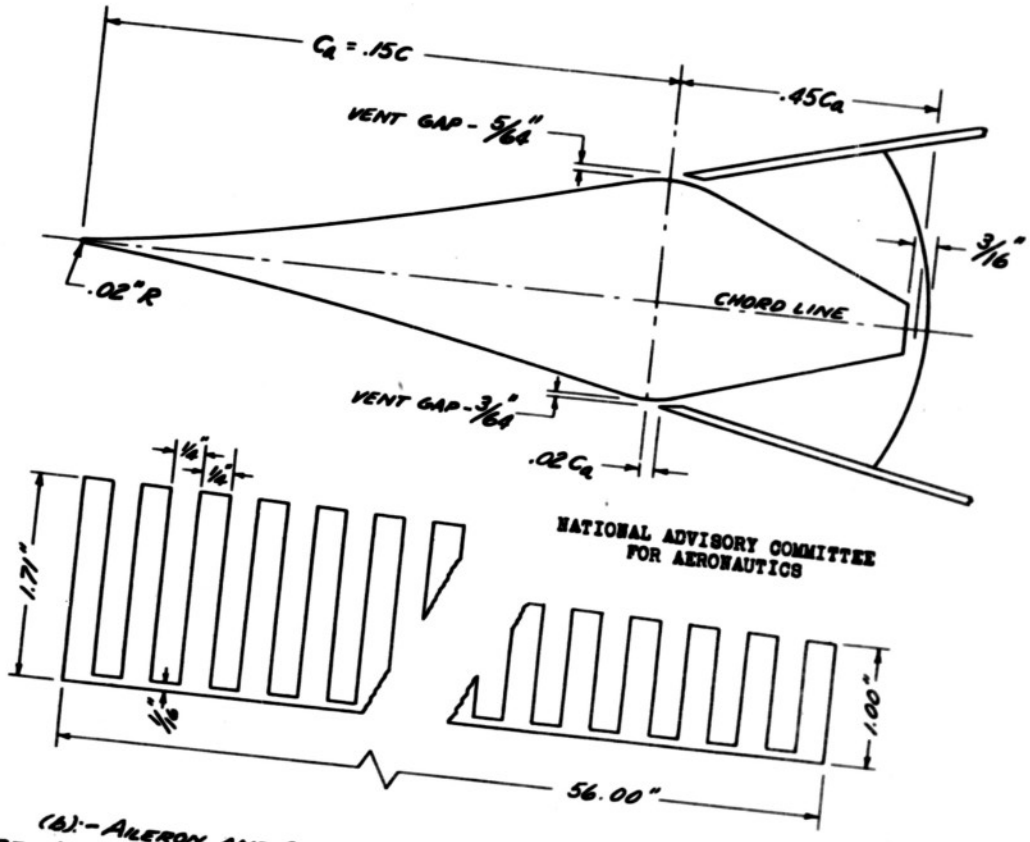


(a):- Tapered wing.

FIGURE 1:- DIMENSIONS OF MODEL.

SPOILER AND AILERON TEST.

Fig. 1a



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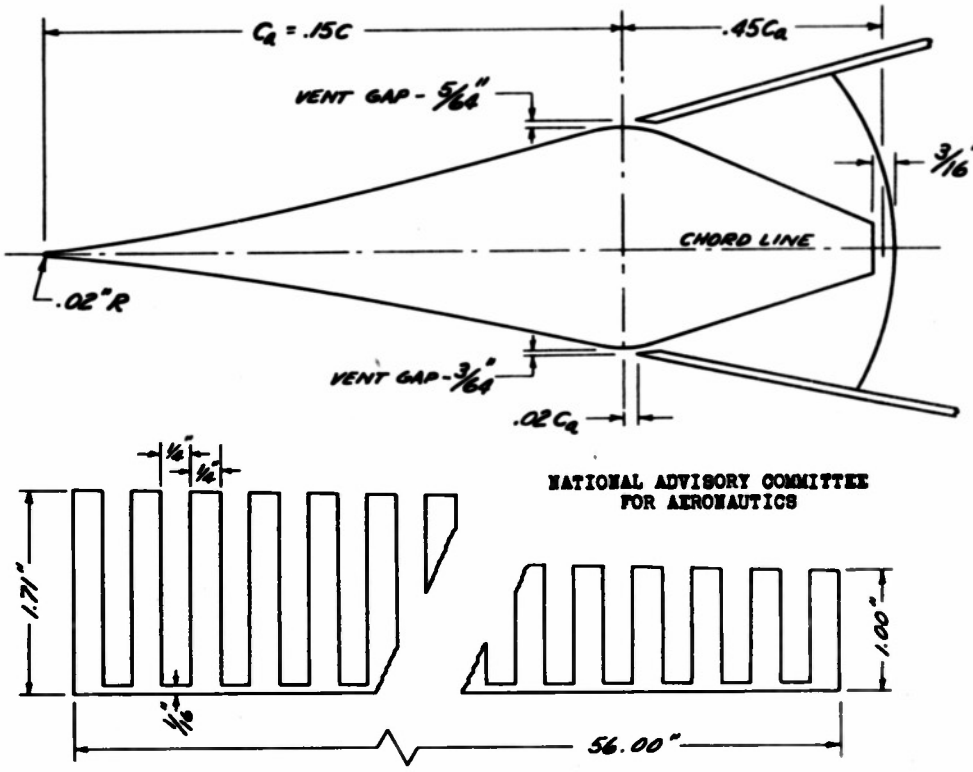
(b):- Aileron and 0.04c slotted spoiler.

FIGURE 1.- Concluded.

Spoiler and aileron test.



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(b):- Aileron and 0.04c slotted spoiler.

FIGURE 1.:- Concluded.

SPOILER AND AILERON TEST.

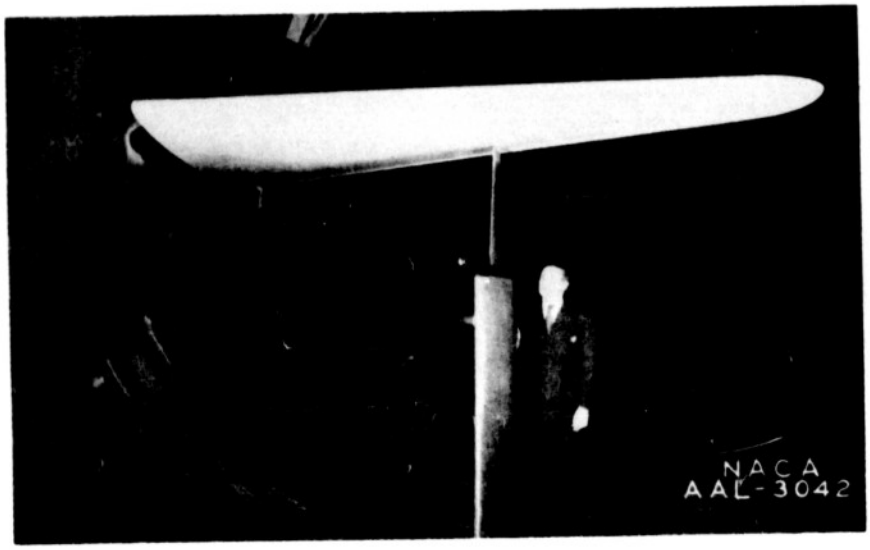


Figure 2.- Tapered wing model mounted in the AAL 16-foot wind tunnel. Spoiler and aileron test.

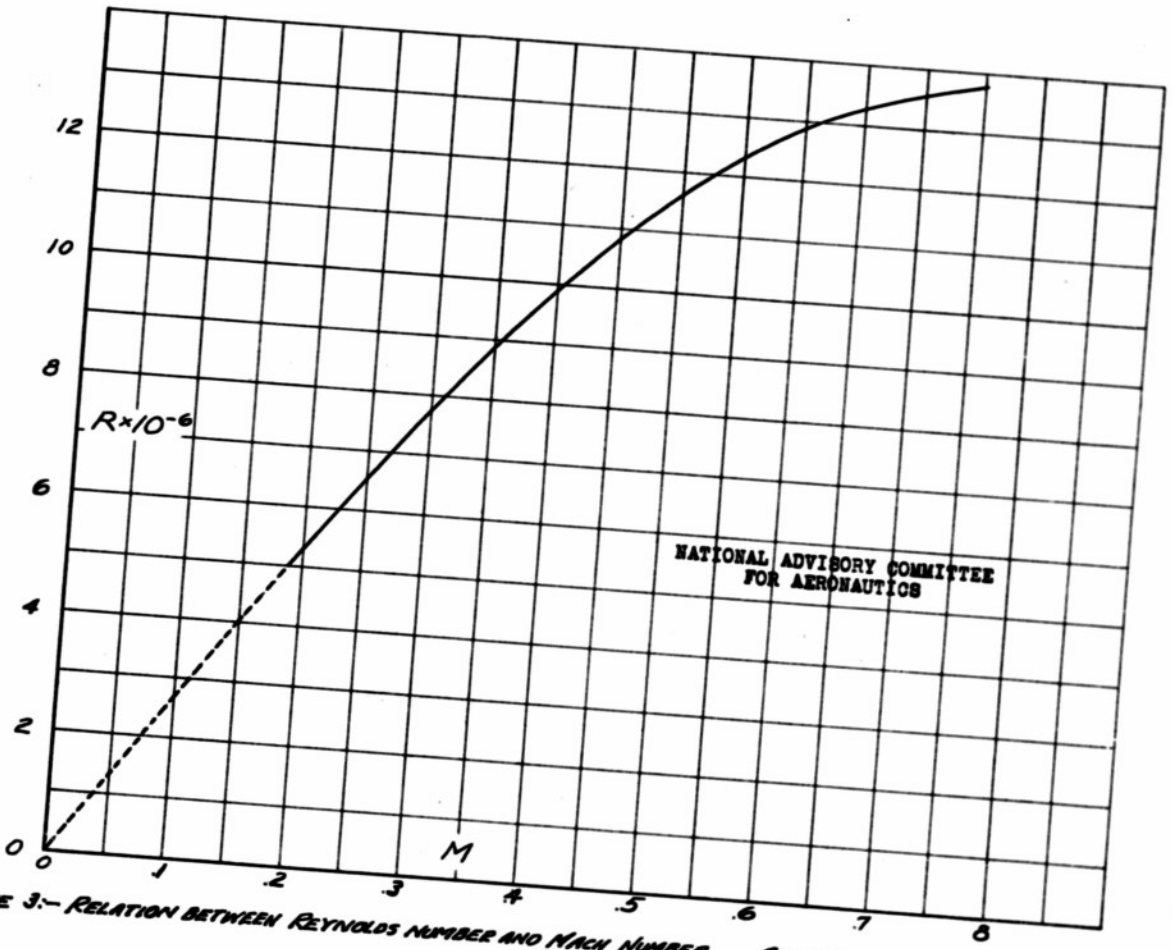
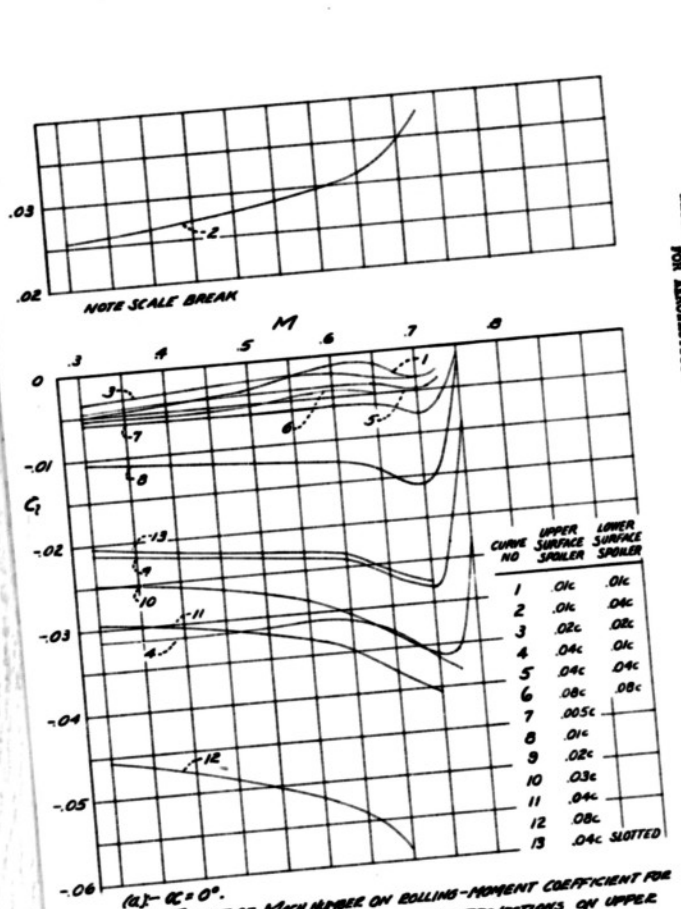
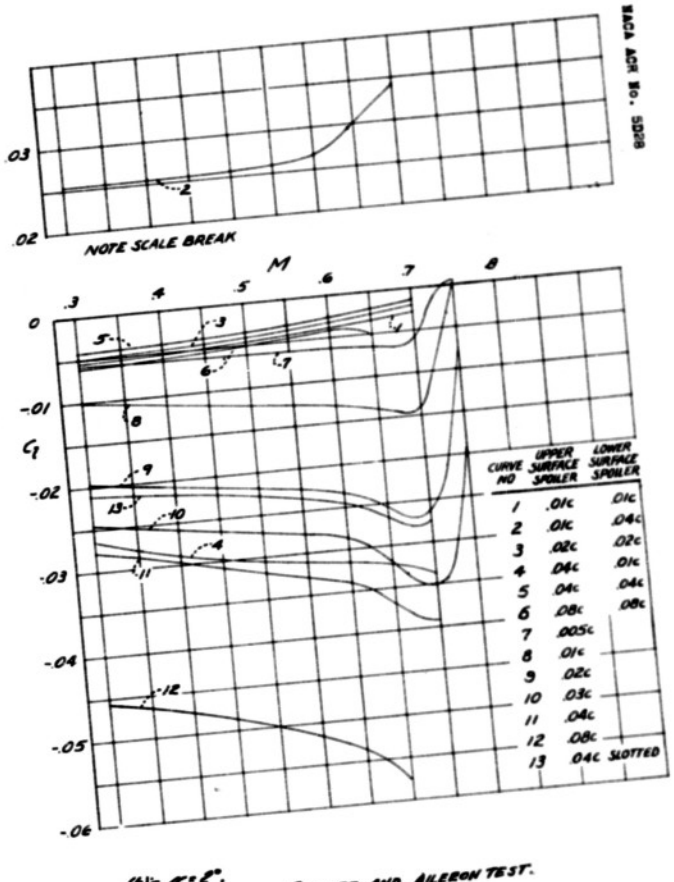


FIGURE 3:- RELATION BETWEEN REYNOLDS NUMBER AND MACH NUMBER. SPOILER AND AILERON TEST.



(a):- $\alpha = 0°$.

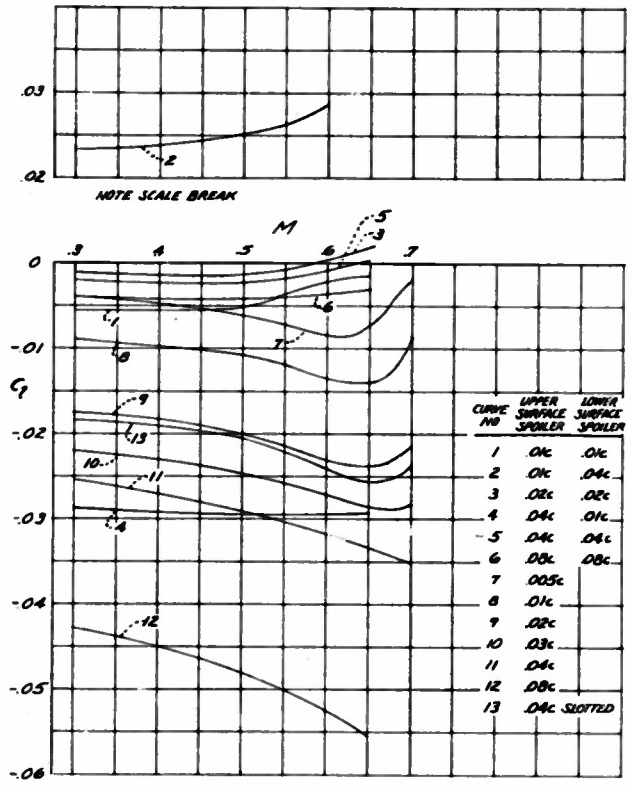
FIGURE 4:- EFFECT OF MACH NUMBER ON ROLLING-MOMENT COEFFICIENT FOR SEVERAL COMBINATIONS OF SPOILER PROJECTIONS ON UPPER AND LOWER SURFACES. $\delta = 0°$ SPOILER AND AILERON TEST.



(b):- $\alpha = 2°$.

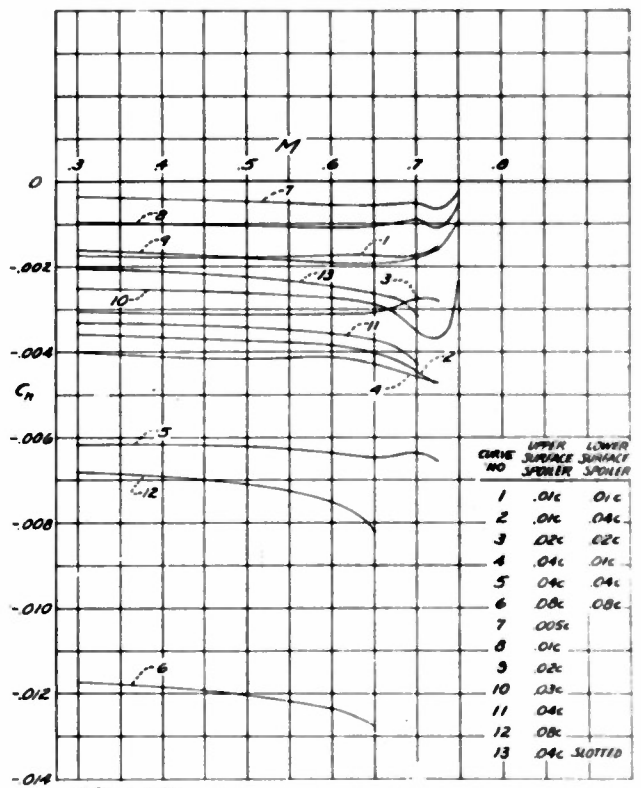
FIGURE 4:- CONTINUED. SPOILER AND AILERON TEST.

FIG. 4a,b



(c)- $\alpha = 4°$.

FIGURE 4:- CONCLUDED. SPOILER AND AILERON TEST.



(a)- $\alpha = 0°$.

FIGURE 5:- EFFECT OF MACH NUMBER ON YAWING-MOMENT COEFFICIENT FOR SEVERAL COMBINATIONS OF SPOILER PROJECTIONS ON UPPER AND LOWER SURFACES. $\delta = 0°$. SPOILER AND AILERON TEST.

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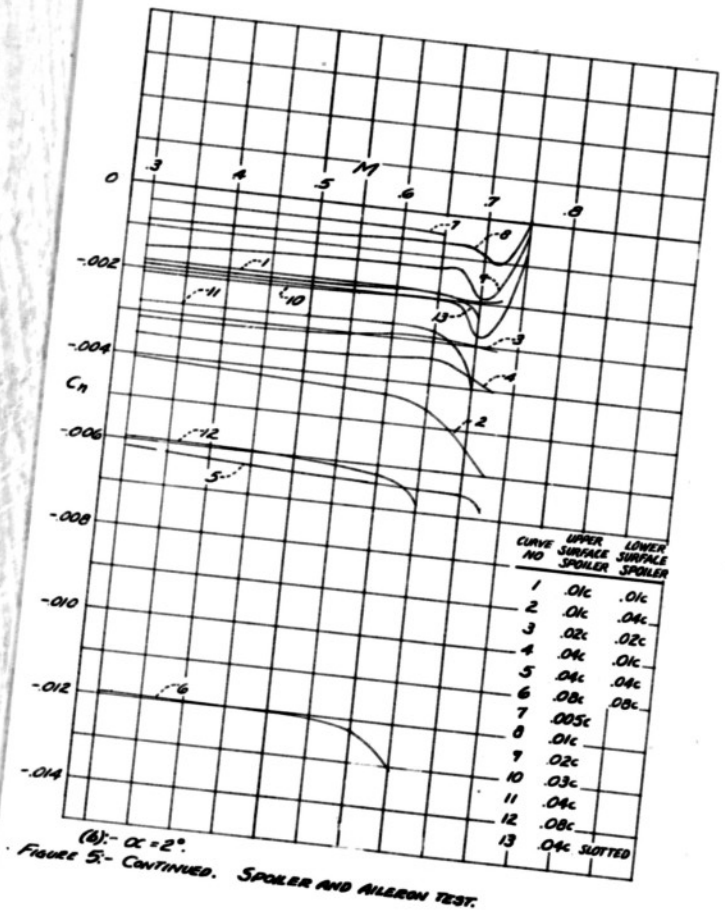
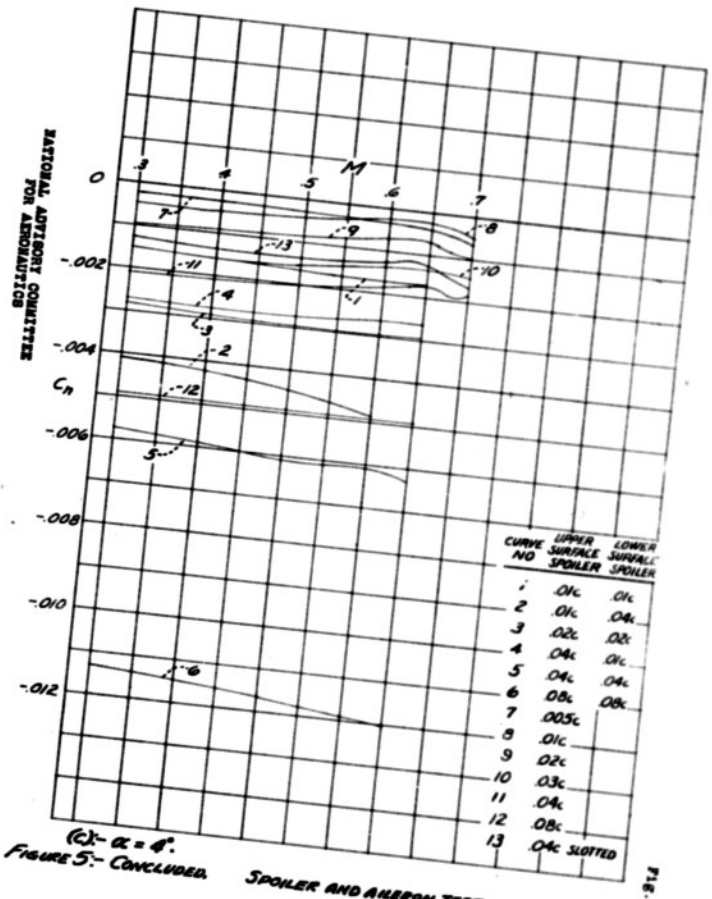


CURVE NO	UPPER SURFACE SPOILER	LOWER SURFACE SPOILER
1	.01c	.01c
2	.01c	.04c
3	.02c	.02c
4	.04c	.01c
5	.04c	.04c
6	.08c	.08c
7	.005c	
8	.01c	
9	.02c	
10	.03c	
11	.04c	
12	.08c	
13	.04c	SLOTTED

(b):- $\alpha = 2°$.

FIGURE 5:- CONTINUED. SPOILER AND AILERON TEST.



CURVE NO	UPPER SURFACE SPOILER	LOWER SURFACE SPOILER
1	.01c	.01c
2	.01c	.04c
3	.02c	.02c
4	.04c	.01c
5	.04c	.04c
6	.08c	.08c
7	.005c	
8	.01c	
9	.02c	
10	.03c	
11	.04c	
12	.08c	
13	.04c	SLOTTED

(c):- $\alpha = 4°$.

FIGURE 5:- CONCLUDED. SPOILER AND AILERON TEST.

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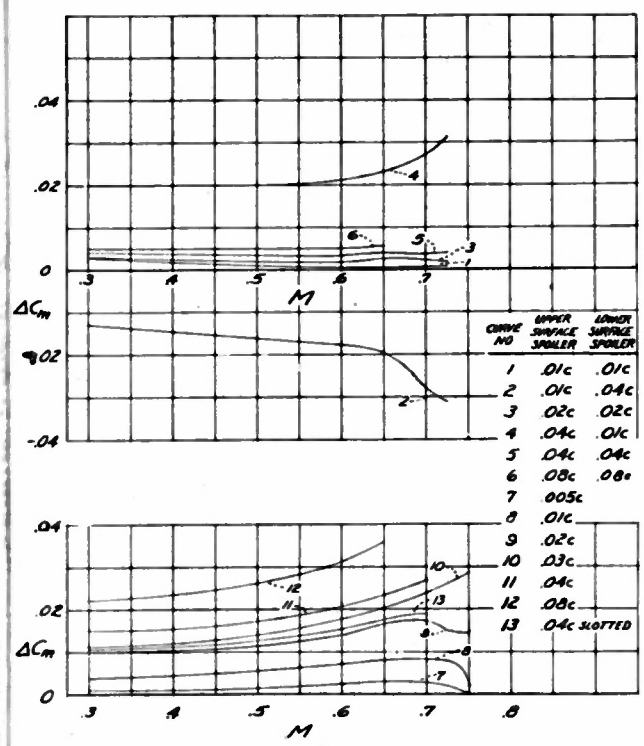

CURVE NO	UPPER SURFACE SPOILER	LOWER SURFACE SPOILER
1	.01c	.01c
2	.01c	.04c
3	.02c	.02c
4	.04c	.01c
5	.04c	.04c
6	.08c	.08c
7	.005c	
8	.01c	
9	.02c	
10	.03c	
11	.04c	
12	.08c	
13	.04c	SLOTTED

(a) $\alpha = 0°$.

FIGURE 6.- EFFECT OF MACH NUMBER ON PITCHING-MOMENT-COEFFICIENT INCREMENT PRODUCED BY SEVERAL COMBINATIONS OF SPOILER PROJECTIONS ON UPPER AND LOWER SURFACES. $\delta = 0°$ SPOILER AND AILERON TEST.

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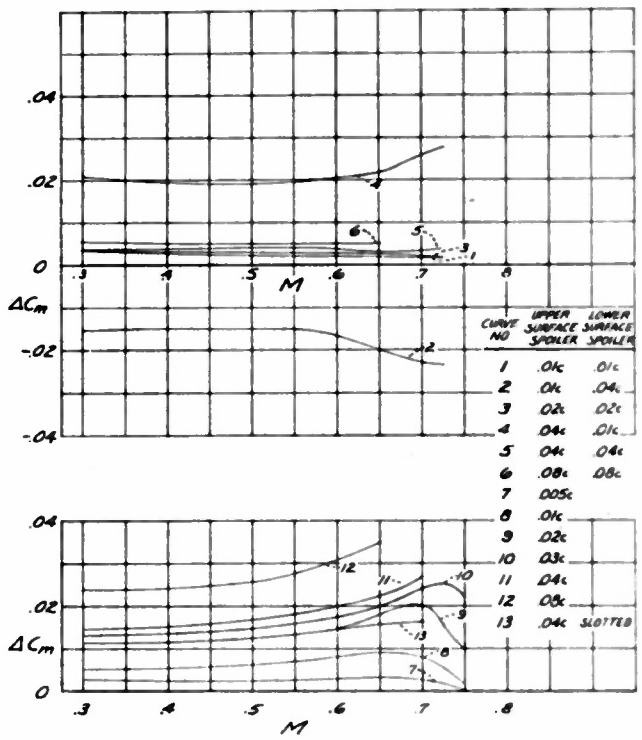
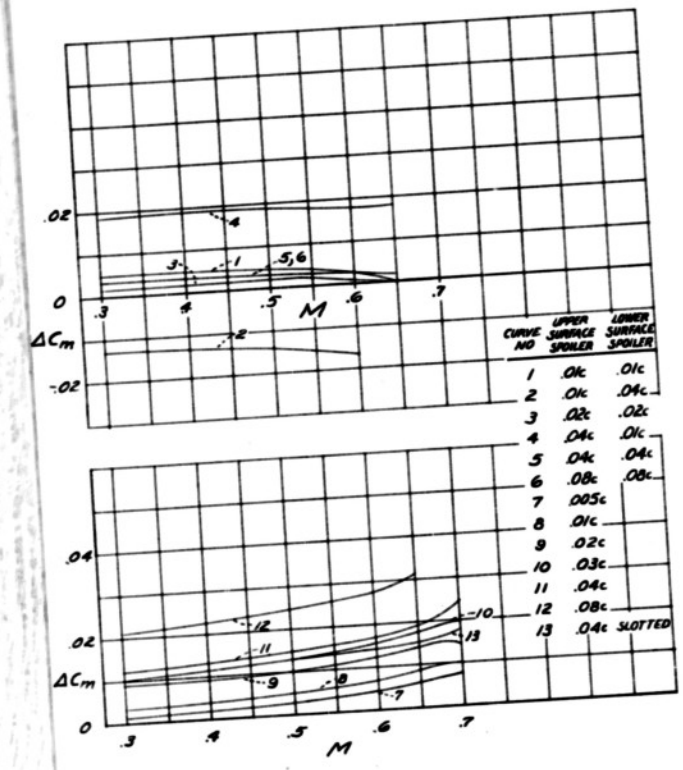


CURVE NO	UPPER SURFACE SPOILER	LOWER SURFACE SPOILER
1	.01c	.01c
2	.01c	.04c
3	.02c	.02c
4	.04c	.01c
5	.04c	.04c
6	.08c	.08c
7	.005c	
8	.01c	
9	.02c	
10	.03c	
11	.04c	
12	.08c	
13	.04c	SLOTTED

(b) $\alpha = 2°$.

FIGURE 6:- CONTINUED. SPOILER AND AILERON TEST.



(c):- $\alpha = 4°$.

FIGURE 6:- CONCLUDED. SPOILER AND AILERON TEST.

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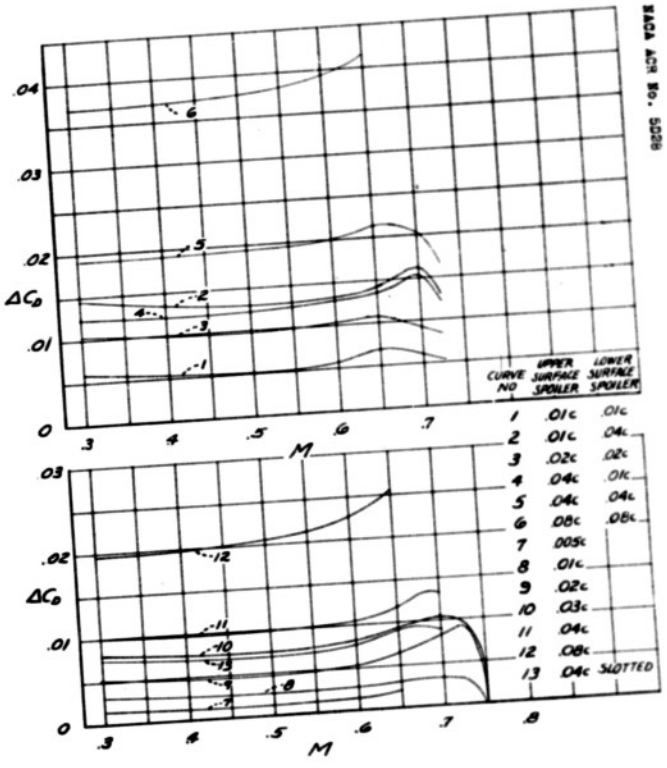
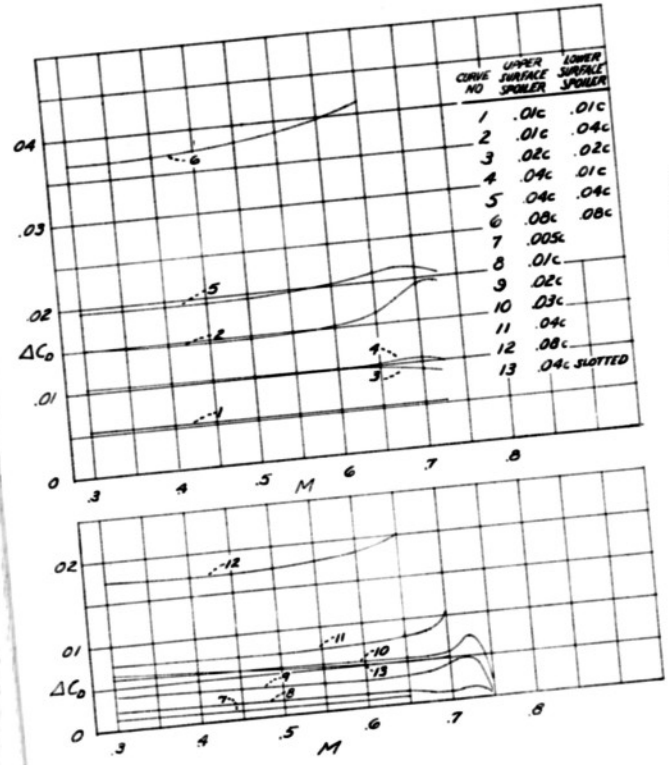


(a):- $\alpha = 0°$.

FIGURE 7:- EFFECT OF MACH NUMBER ON DRAG-COEFFICIENT INCREMENT PRODUCED BY SEVERAL COMBINATIONS OF SPOILER PROJECTIONS ON UPPER AND LOWER SURFACES. $\delta = 0°$. SPOILER AND AILERON TEST.



(b):- $\alpha = 2°$.
FIGURE 7:- CONTINUED. SPOILER AND AILERON TEST.

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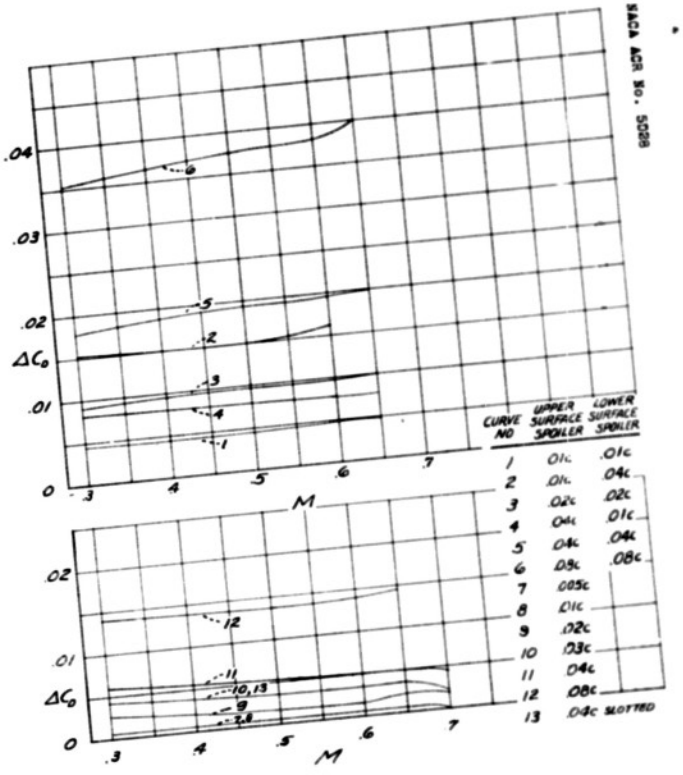
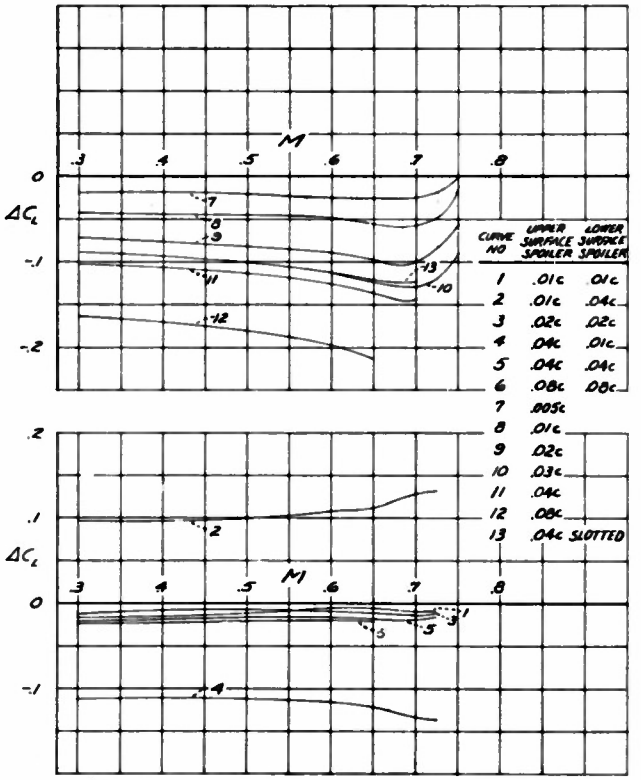


(c):- $\alpha = 4°$.
FIGURE 7:- CONCLUDED. SPOILER AND AILERON TEST.



(a):- $\alpha = 0°$.

FIGURE 8:- EFFECT OF MACH NUMBER ON LIFT-COEFFICIENT INCREMENT PRODUCED BY SEVERAL SPOILER COMBINATIONS ON UPPER AND LOWER SURFACES. $\delta = 0°$. SPOILER AND AILERON TEST.

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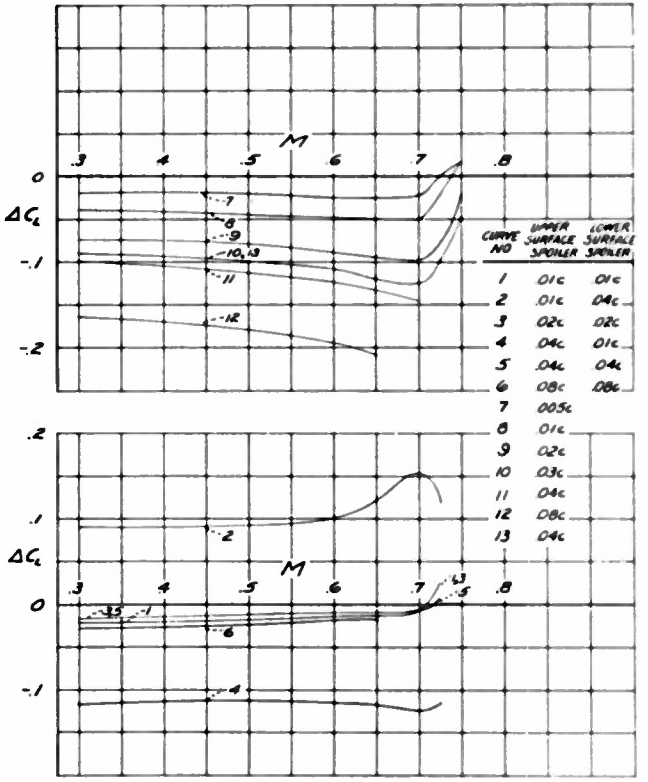

(b):- $\alpha = 2°$.

FIGURE 8:- CONTINUED. SPOILER AND AILERON TEST.

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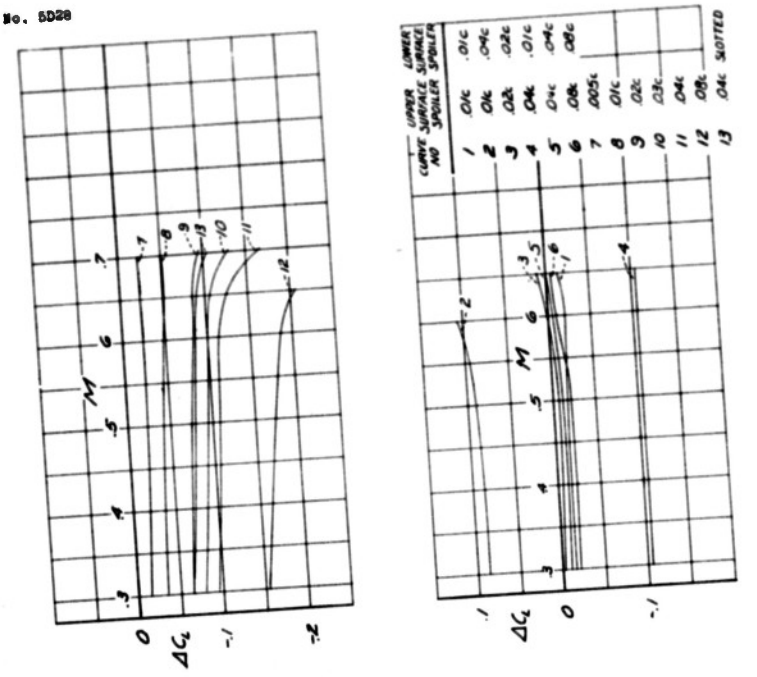

(a) $\alpha - \alpha = 4°$.

FIGURE 8:- CONCLUDED. SPOILER AND AILERON TEST.

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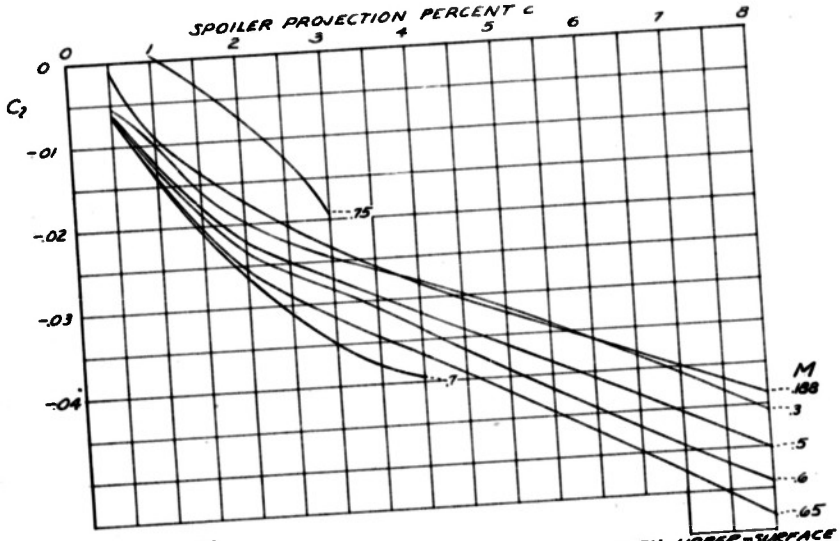
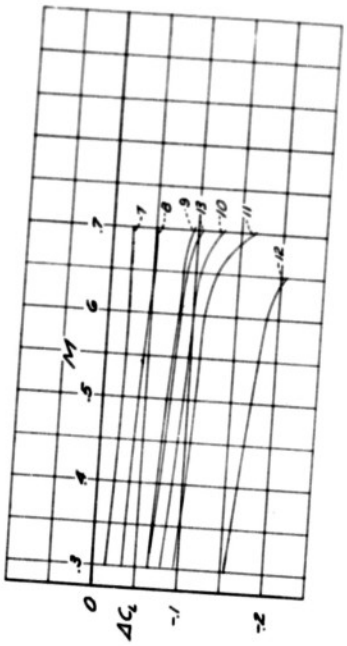
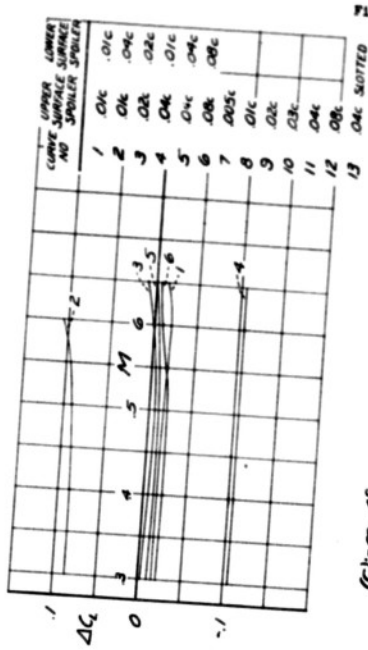


(a) $\alpha - \alpha = 2°$.

FIGURE 9:- VARIATION OF ROLLING-MOMENT COEFFICIENT WITH UPPER-SURFACE SPOILER PROJECTION. $\delta = 0°$. SPOILER AND AILERON TEST.

Figs. 8c, 9a





(a) $\alpha = 4°$.

FIGURE 8:- CONCLUDED. SPOILER AND AILERON TEST.

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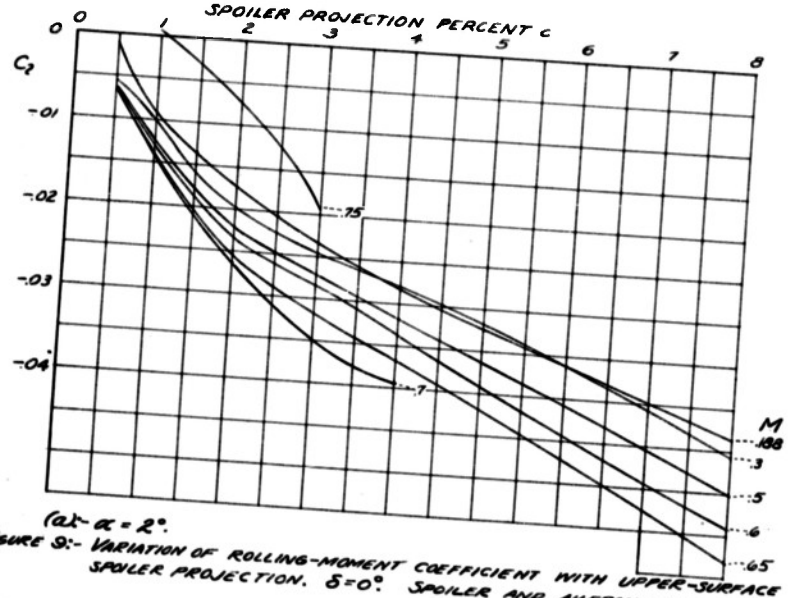
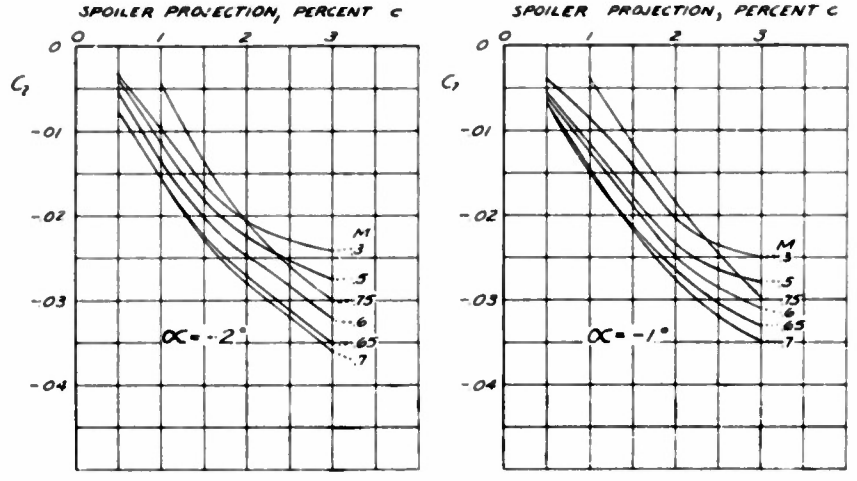


(a) $\alpha = 2°$.

FIGURE 9:- VARIATION OF ROLLING-MOMENT COEFFICIENT WITH UPPER-SURFACE SPOILER PROJECTION. $\delta = 0°$. SPOILER AND AILERON TEST.



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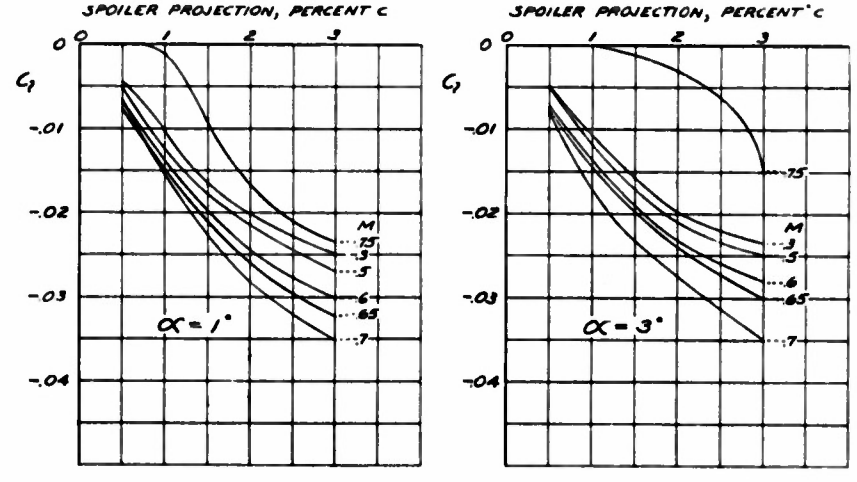
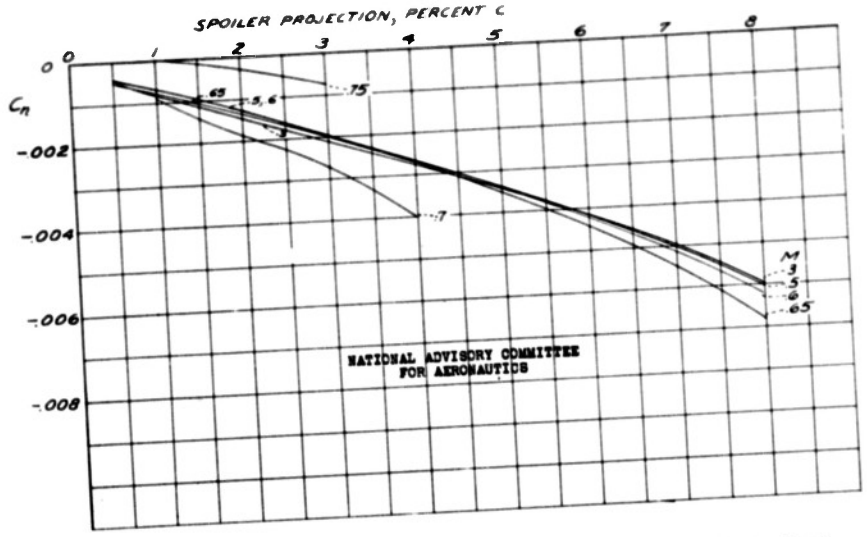
(b).- $\alpha = -2°$ AND $-1°$.

FIGURE 9.- CONTINUED. SPOILER AND AILERON TEST



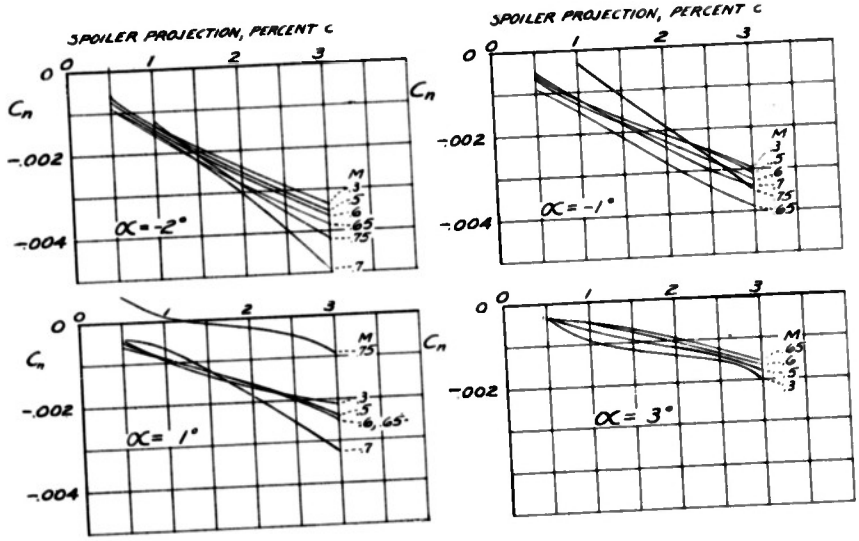
(c).- $\alpha = 1°$ AND $3°$.

FIGURE 9.- CONCLUDED. SPOILER AND AILERON TEST.



(a):- $\alpha = 2°$.

FIGURE 10:- VARIATION OF YAWING-MOMENT COEFFICIENT WITH UPPER-SURFACE SPOILER PROJECTION. $\delta = 0°$. SPOILER AND AILERON TEST.



(b):- $\alpha = -2°, -1°, 1°$ AND $3°$.

FIGURE 10:- CONCLUDED. SPOILER AND AILERON TEST.

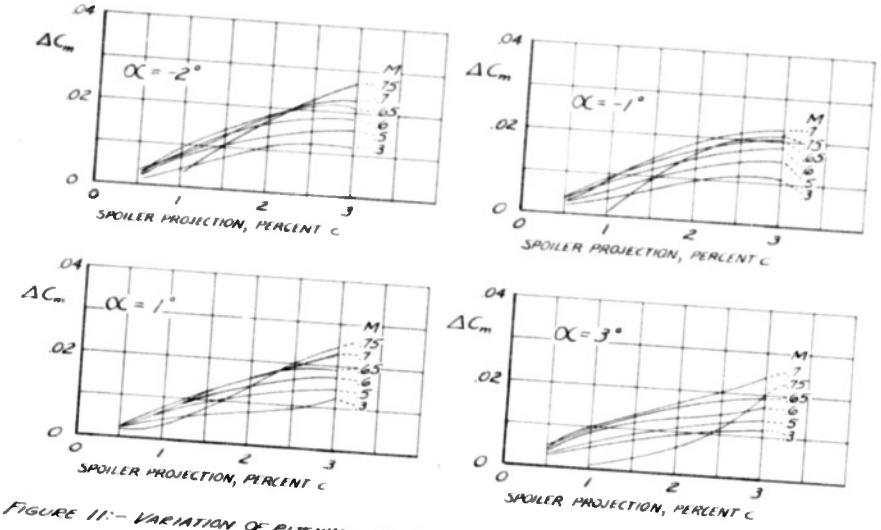


FIGURE 11:- VARIATION OF PITCHING-MOMENT-COEFFICIENT INCREMENT WITH UPPER-SURFACE SPOILER PROJECTION. $\delta = 0°$. SPOILER AND AILERON TEST.

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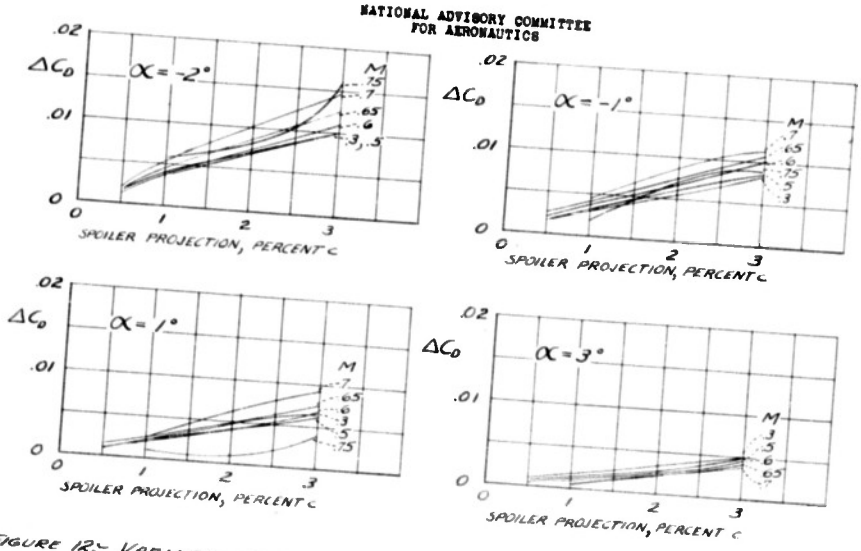

FIGURE 12:- VARIATION OF DRAG-COEFFICIENT INCREMENT WITH UPPER-SURFACE SPOILER PROJECTION. $\delta = 0°$. SPOILER AND AILERON TEST.

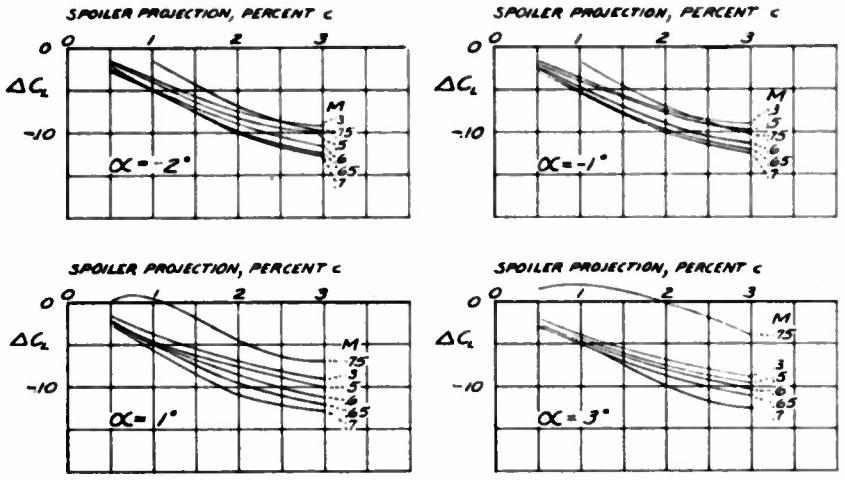

FIGURE 13.- VARIATION OF LIFT - COEFFICIENT INCREMENT WITH UPPER-SURFACE SPOILER PROJECTION. $\delta = 0°$. SPOILER AND AILERON TEST.

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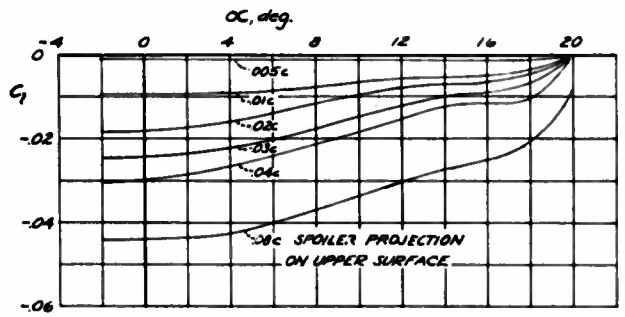


FIGURE 14.- VARIATION OF ROLLING-MOMENT COEFFICIENT WITH ANGLE OF ATTACK. $M = 0.18$; $R = 6,000,000$; $\delta = 0°$. SPOILER AND AILERON TEST.

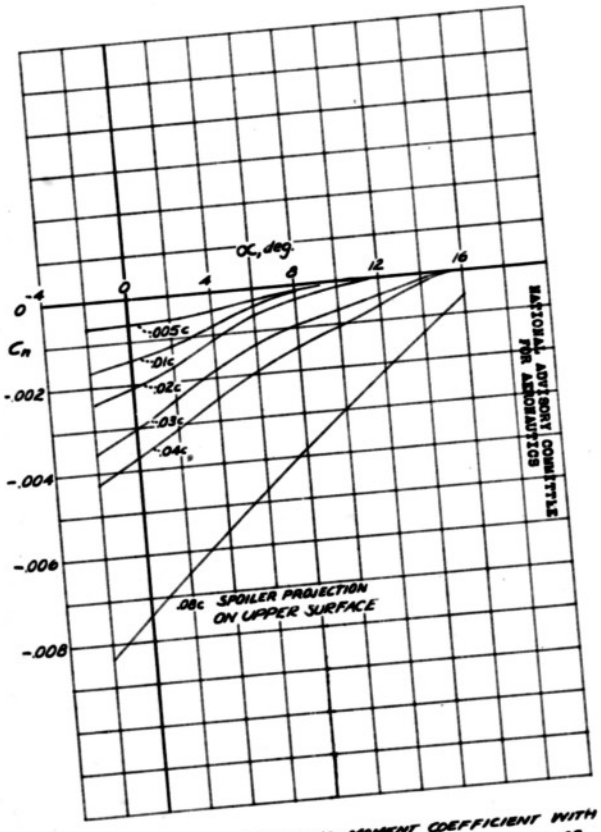
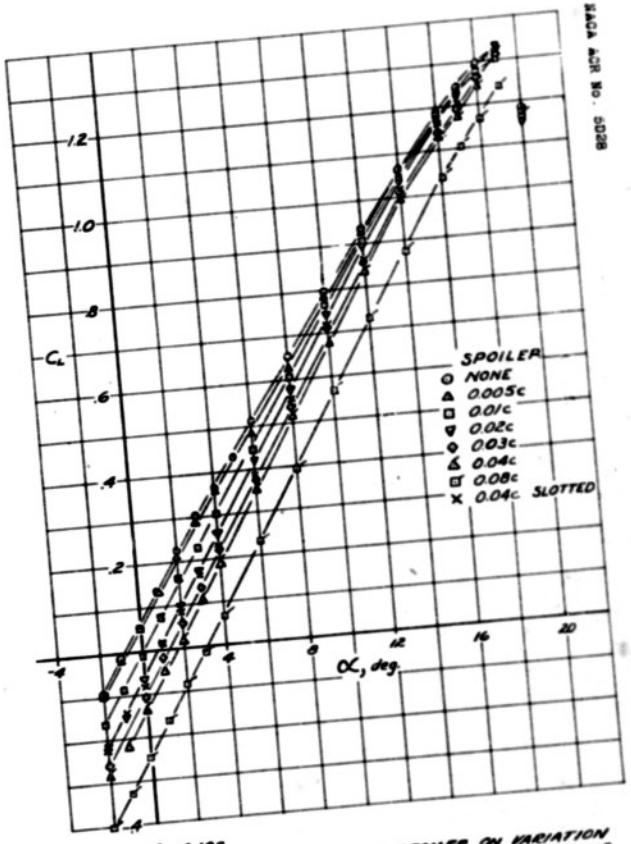


FIGURE 15.:- VARIATION OF YAWING-MOMENT COEFFICIENT WITH ANGLE OF ATTACK. M=0.188; R=5,000,000; δ=0°. SPOILER AND AILERON TEST.



(a):- M = 0.188.

FIGURE 16:- EFFECT OF UPPER-SURFACE SPOILER ON VARIATION OF LIFT COEFFICIENT WITH ANGLE OF ATTACK. δ=0°. SPOILER AND AILERON TEST.

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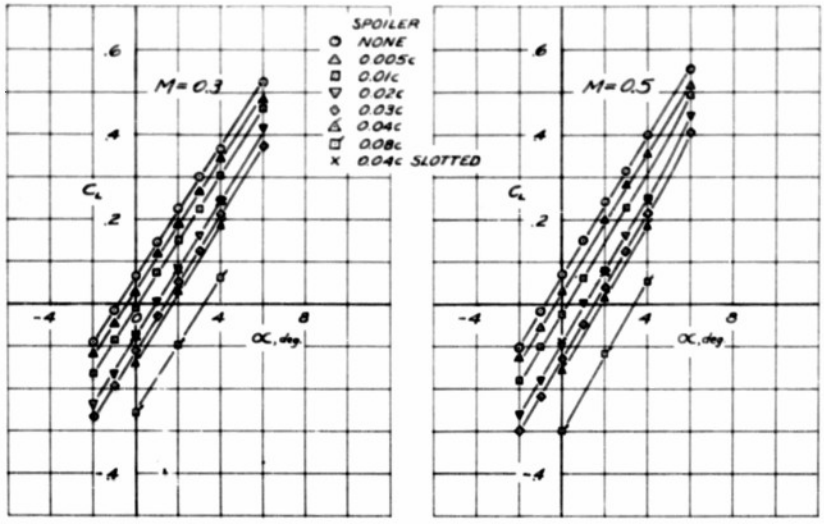

(b):- M = 0.3 AND 0.5.
FIGURE 16:- CONTINUED. SPOILER AND AILERON TEST.

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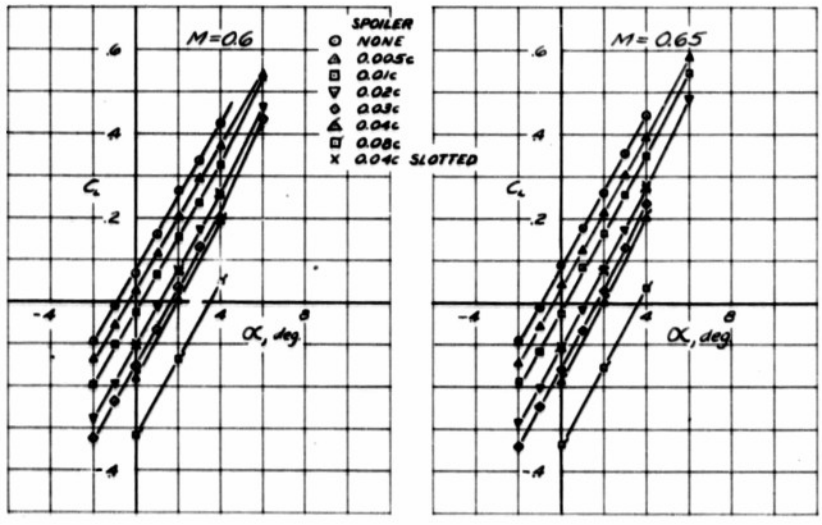

(c):- M = 0.6 AND 0.65.
FIGURE 16:- CONTINUED. SPOILER AND AILERON TEST.

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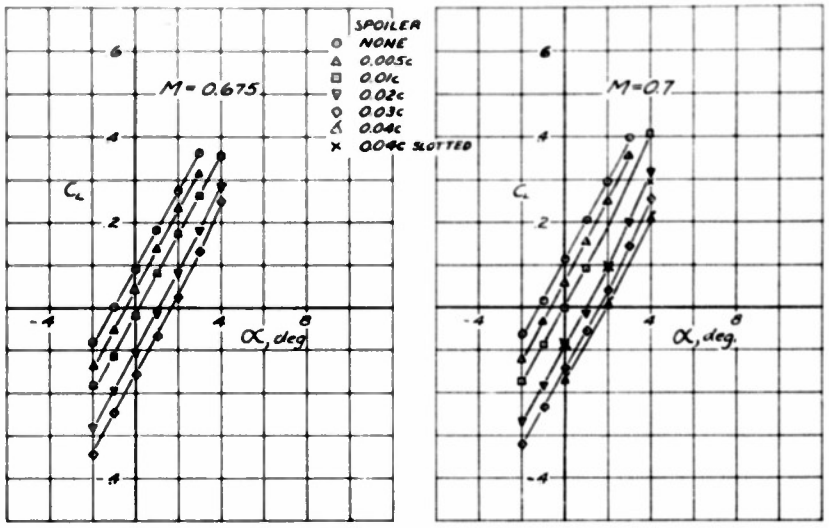

(d):- M = 0.675 AND 0.7.
FIGURE 16:- CONTINUED. SPOILER AND AILERON TEST.

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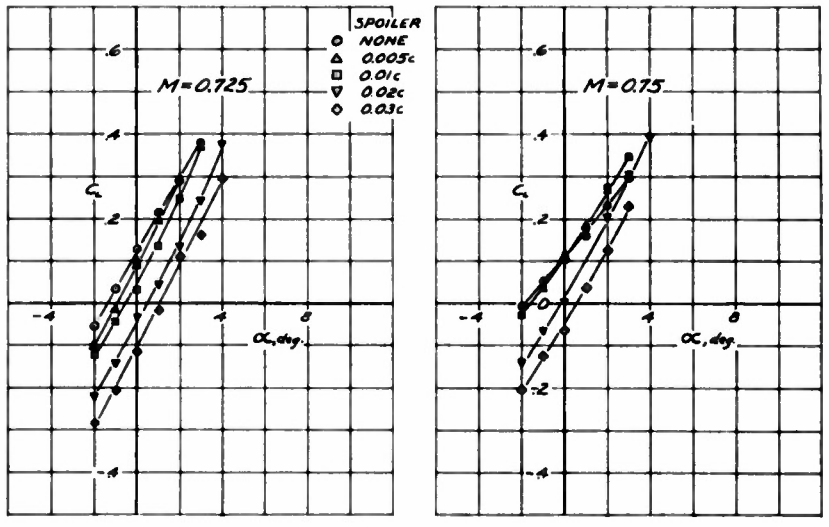
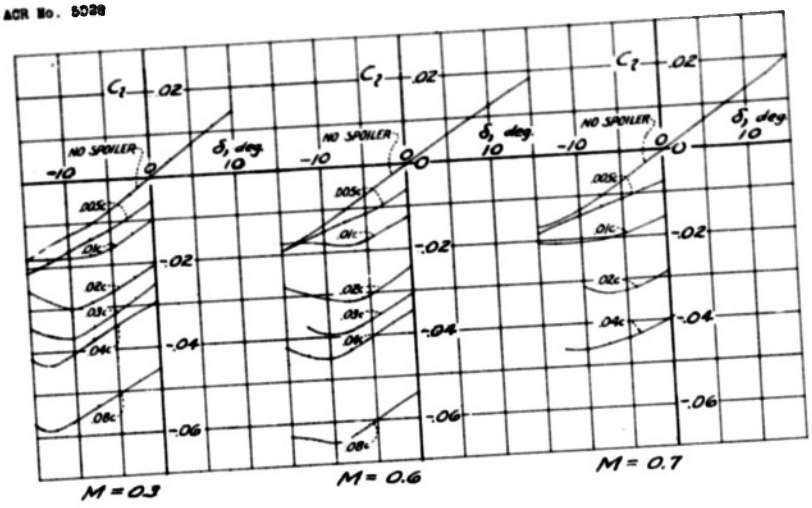


(e):- M = 0.725 AND 0.75.
FIGURE 16:- CONCLUDED. SPOILER AND AILERON TEST.



(a):- $\alpha = 0°$.

FIGURE 17.- VARIATION OF ROLLING-MOMENT COEFFICIENT WITH AILERON DEFLECTION. AILERON UN-SEALED; UPPER-SURFACE SPOILERS. SPOILER AND AILERON TEST.

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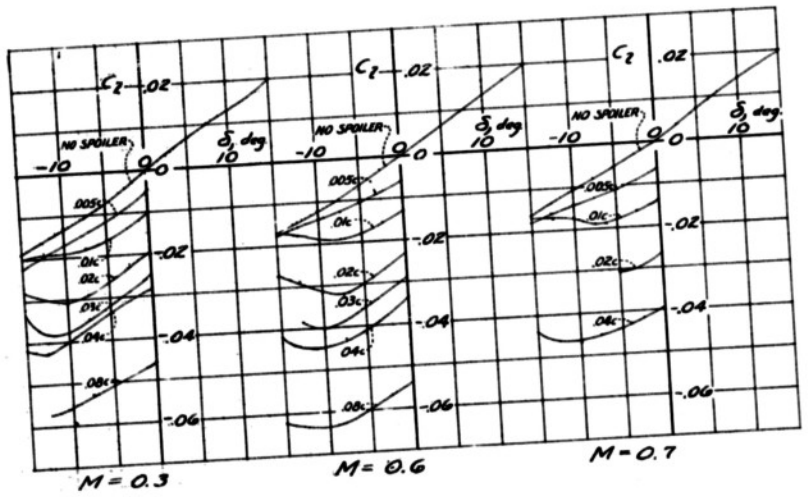
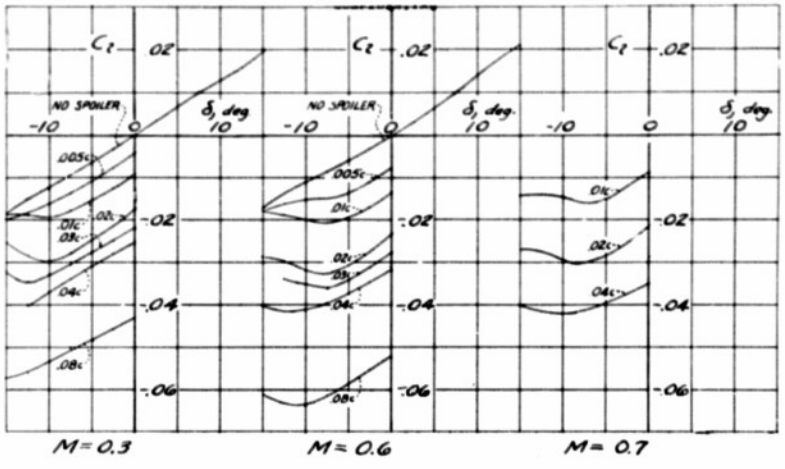


(b):- $\alpha = 2°$.

FIGURE 17.- CONTINUED. SPOILER AND AILERON TEST.

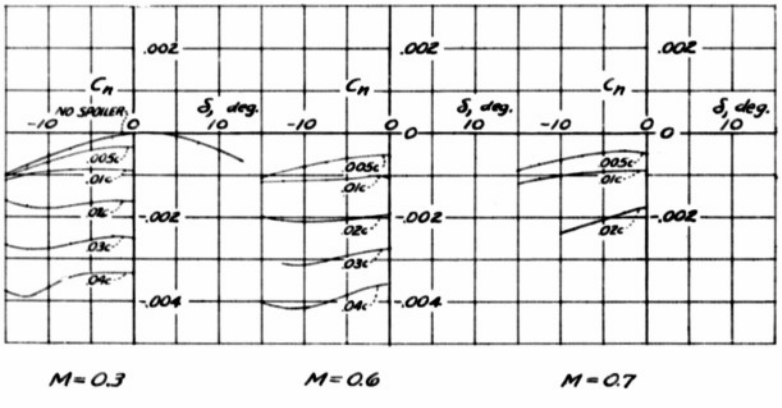
A-21



(c):- $\alpha = 4°$.

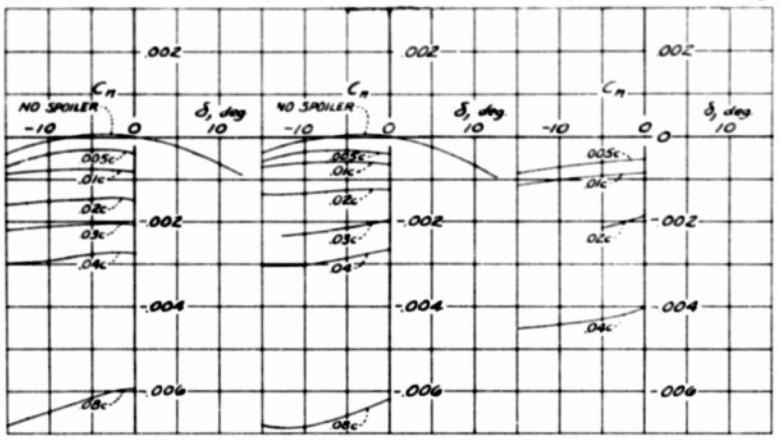
FIGURE 17.- CONCLUDED. SPOILER AND AILERON TEST.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



(a):- $\alpha = 0°$.

FIGURE 18.- VARIATION OF YAWING-MOMENT COEFFICIENT WITH AILERON DEFLECTION. AILERON UN-SEALED; UPPER-SURFACE SPOILERS. SPOILER AND AILERON TEST.



M = 0.3 M = 0.6 M = 0.7

(b).- $\alpha = 2°$.

FIGURE 18.- CONTINUED. SPOILER AND AILERON TEST.

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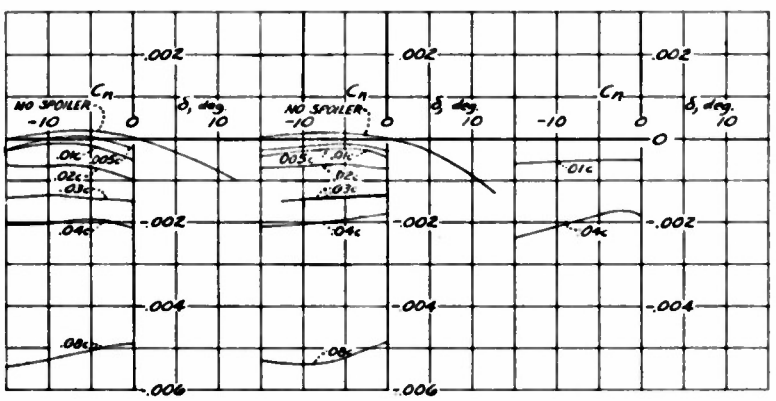
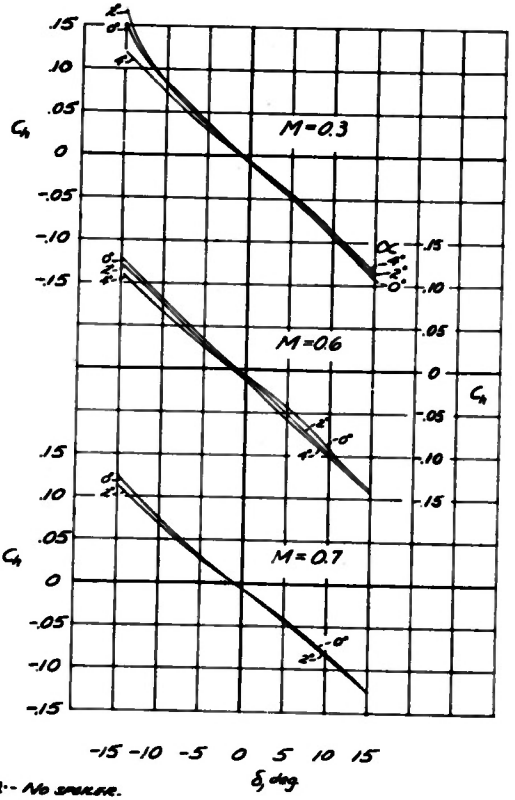


M = 0.3 M = 0.6 M = 0.7

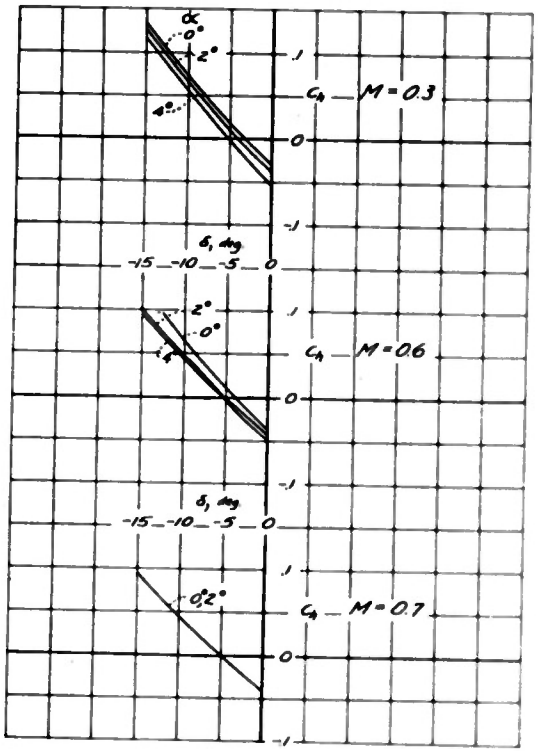
(c).- $\alpha = 4°$.

FIGURE 18.- CONCLUDED. SPOILER AND AILERON TEST.



(a):- No spoiler.

FIGURE 19:- VARIATION OF AILERON HINGE-MOMENT COEFFICIENT WITH AILERON DEFLECTION. AILERON UN-SEALED. SPOILER AND AILERON TEST.



(b):- 0.005c spoiler on upper surface.

FIGURE 19:- CONTINUED. SPOILER AND AILERON TEST.

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Fig. 19a,b

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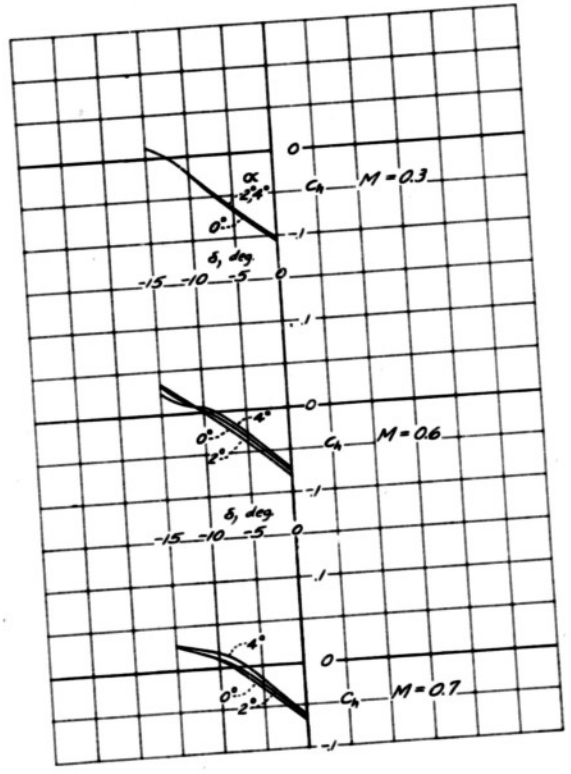
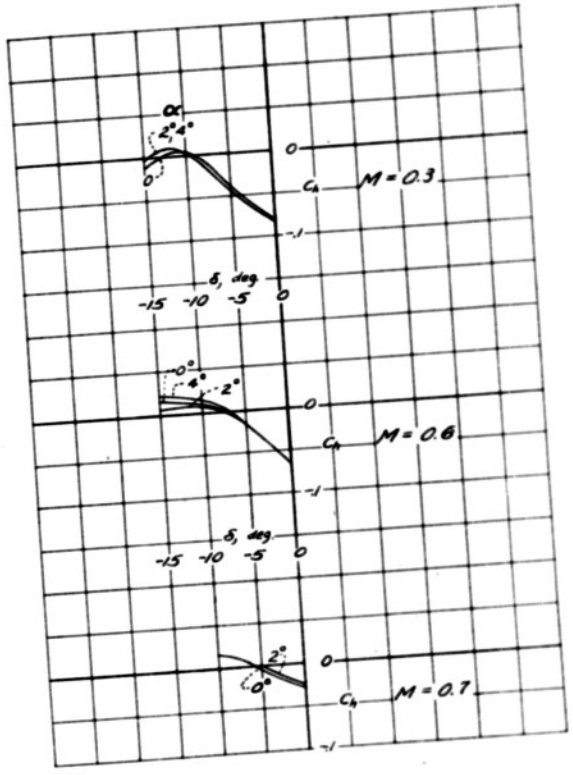


(c)- 0.01c SPOILER ON UPPER SURFACE.
FIGURE 19.- CONTINUED. SPOILER AND AILERON TEST.



(d)- 0.02c SPOILER ON UPPER SURFACE.
FIGURE 19.- CONTINUED. SPOILER AND AILERON TEST.

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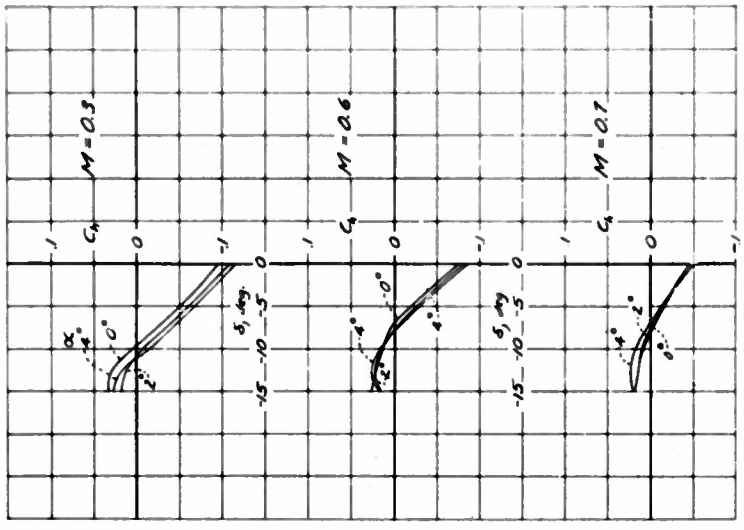

(f):- 0.08c spoiler on upper surface.
FIGURE 19:- Continued. Spoiler and aileron test.

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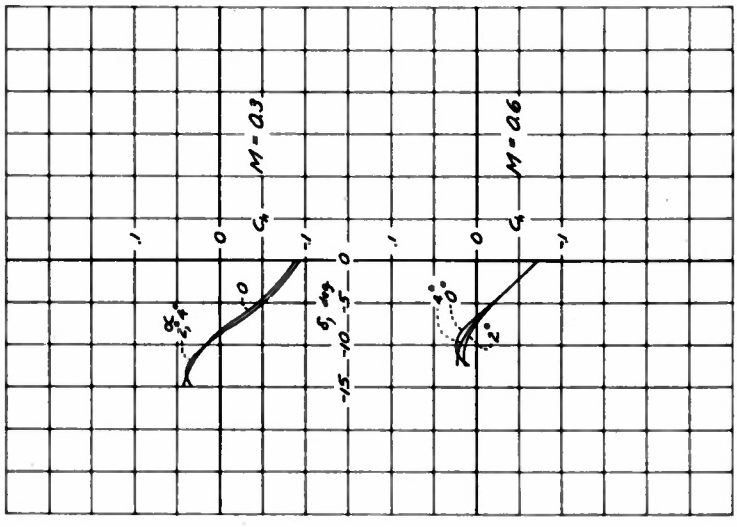
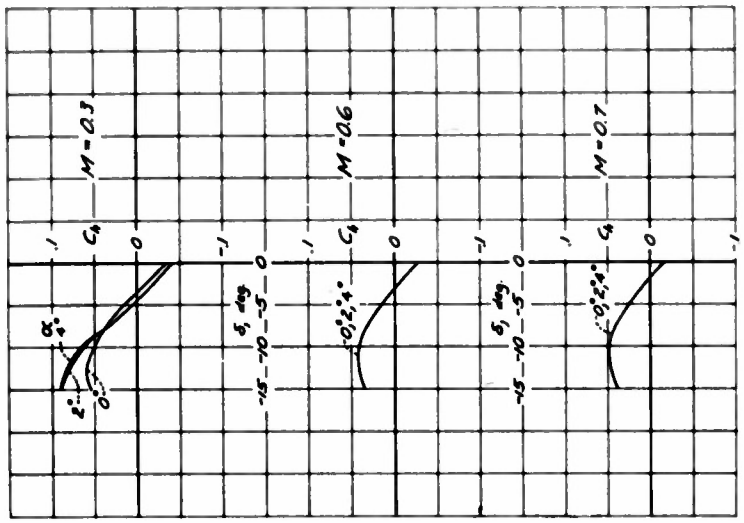


(g):- 0.15c spoiler on upper surface.
FIGURE 19:- Continued. Spoiler and aileron test.



(h):- 0.04c SLOTTED SPOILER ON UPPER SURFACE.
FIGURE 19:- CONTINUED. SPOILER AND AILERON TEST

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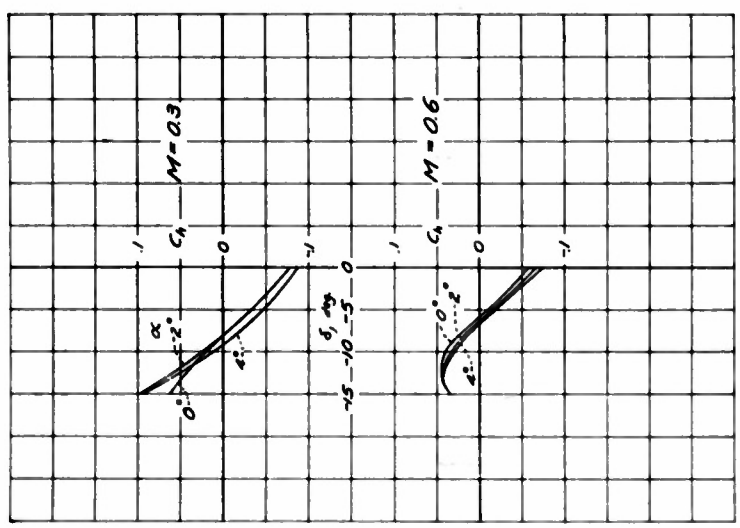
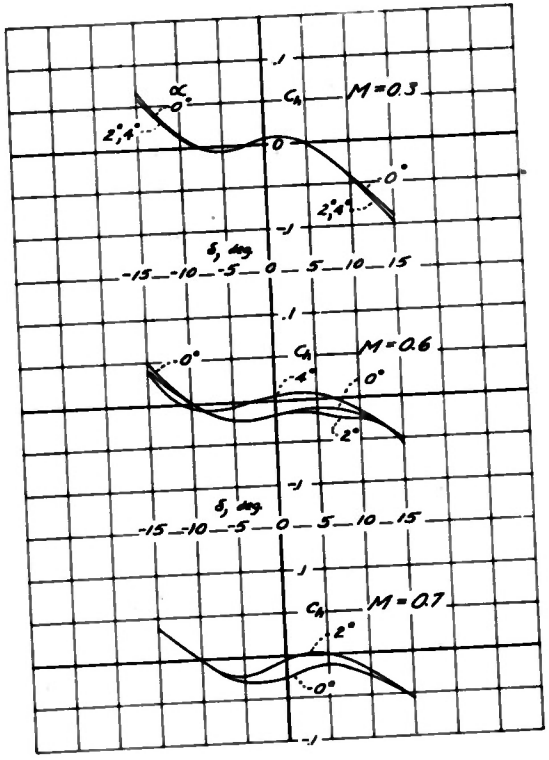


(g):- 0.08c SPOILER ON UPPER SURFACE.
FIGURE 19:- CONTINUED. SPOILER AND AILERON TEST.



(i):- 0.01c SPOILER ON BOTH UPPER AND LOWER SURFACES.

FIGURE 19:- CONCLUDED. SPOILER AND AILERON TEST.

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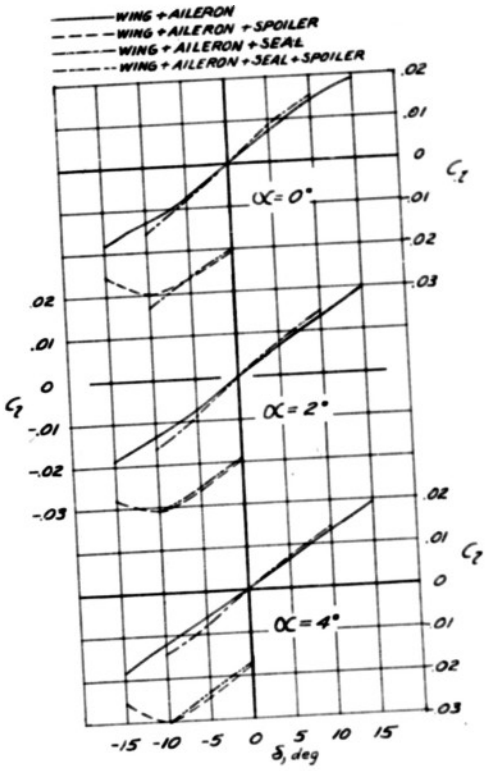
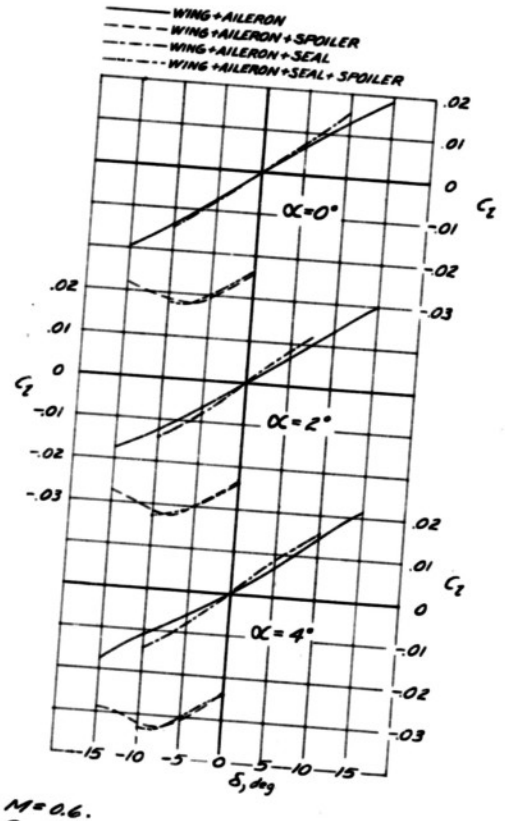


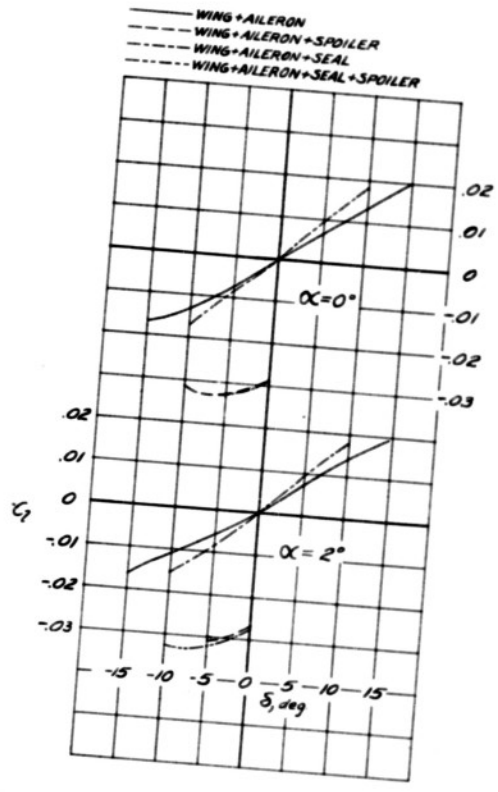
(a):- M = 0.3.

FIGURE 20:- EFFECT OF SEAL ON ROLLING-MOMENT COEFFICIENT FOR WING ALONE AND WING WITH SPOILER PROJECTION OF 0.02c ON UPPER SURFACE. SPOILER AND AILERON TEST.



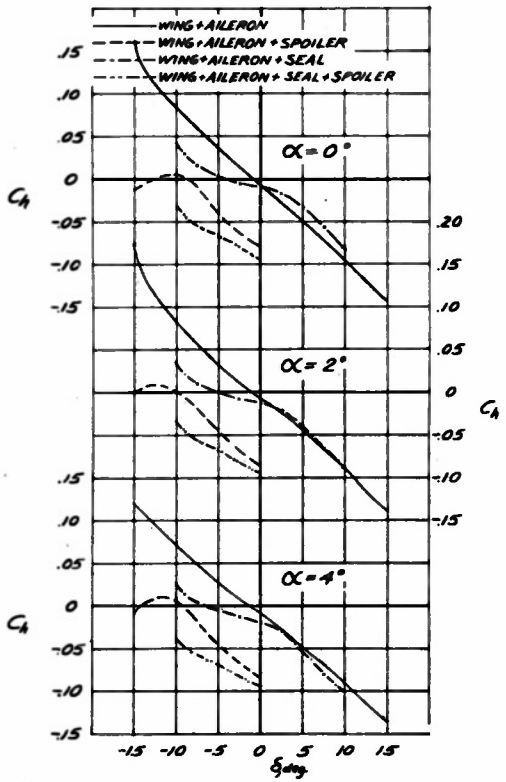
(b):- M = 0.6.

FIGURE 20:- CONTINUED. SPOILER AND AILERON TEST.



(c):- M = 0.7.

FIGURE 20:- CONCLUDED. SPOILER AND AILERON TEST.



(a):- $M = 0.3$.

FIGURE 21.- EFFECT OF SEAL ON AILERON HINGE-MOMENT COEFFICIENT FOR WING ALONE AND WING WITH SPOILER PROJECTION OF 0.02c ON UPPER SURFACE. SPOILER AND AILERON TEST.

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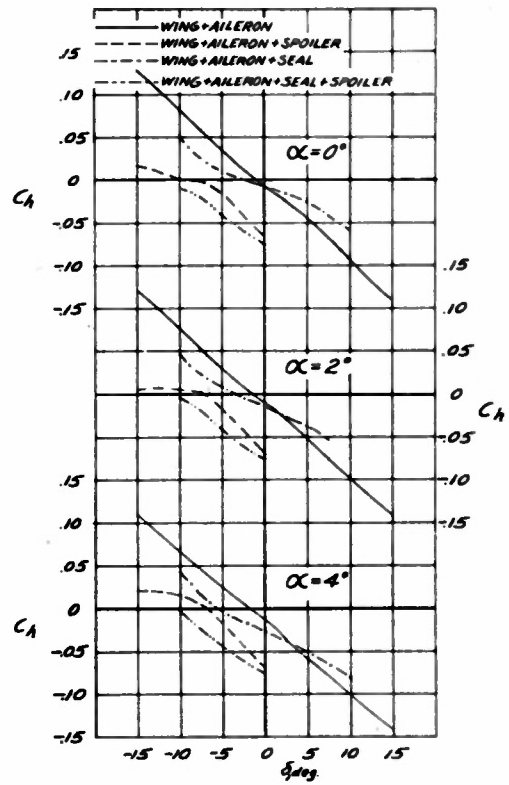

(b):- $M = 0.6$.

FIGURE 21.- CONTINUED. SPOILER AND AILERON TEST.

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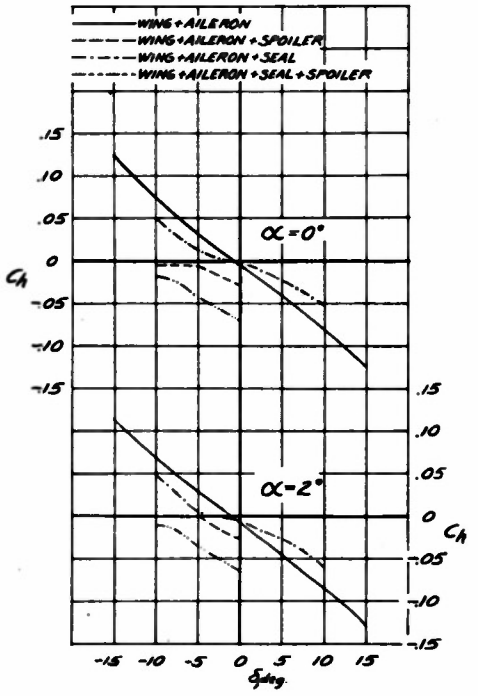
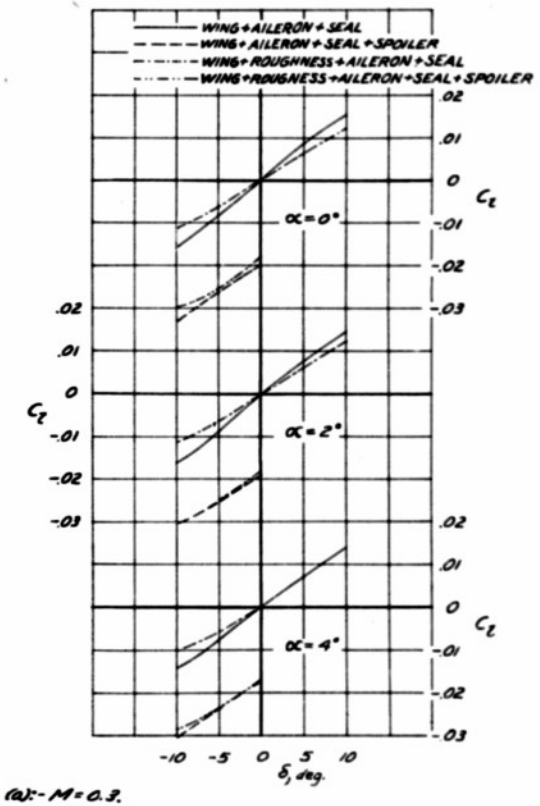
Fig. 21a,b



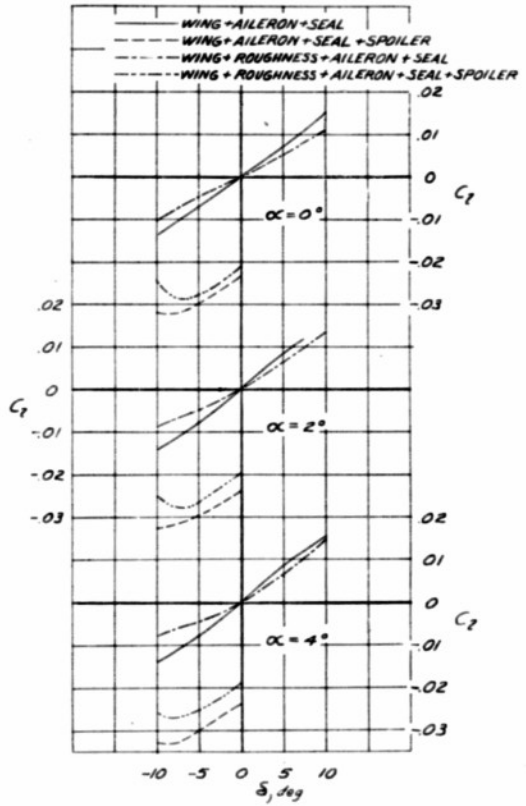
(c):- M = 0.7.

FIGURE 21.- CONCLUDED. SPOILER AND AILERON TEST.

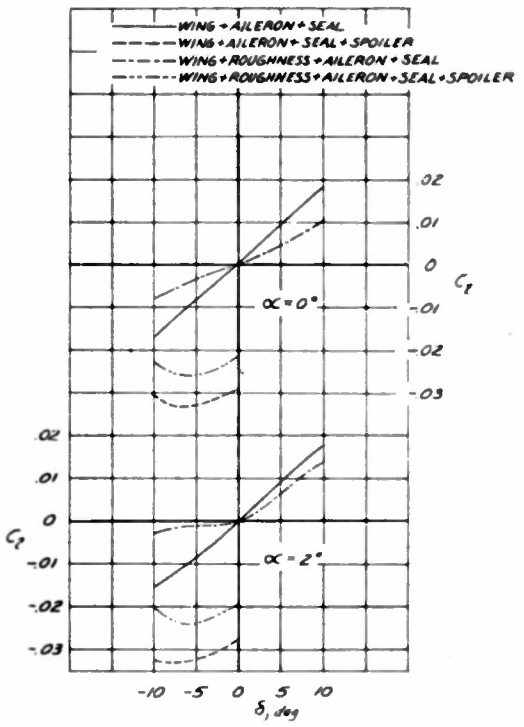


(a):- M = 0.3.

FIGURE 22.- EFFECT OF ROUGHNESS AT 0.02c ON ROLLING-MOMENT COEFFICIENT FOR WING ALONE AND WING WITH SPOILER PROJECTION OF 0.02c ON UPPER SURFACE. AILERON SEALED. SPOILER AND AILERON TEST.



(b):- M = 0.6.
FIGURE 22.- CONTINUED. SPOILER AND AILERON TEST.



(c):- M = 0.7.
FIGURE 22.- CONCLUDED. SPOILER AND AILERON TEST.

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FIG. 22b,c

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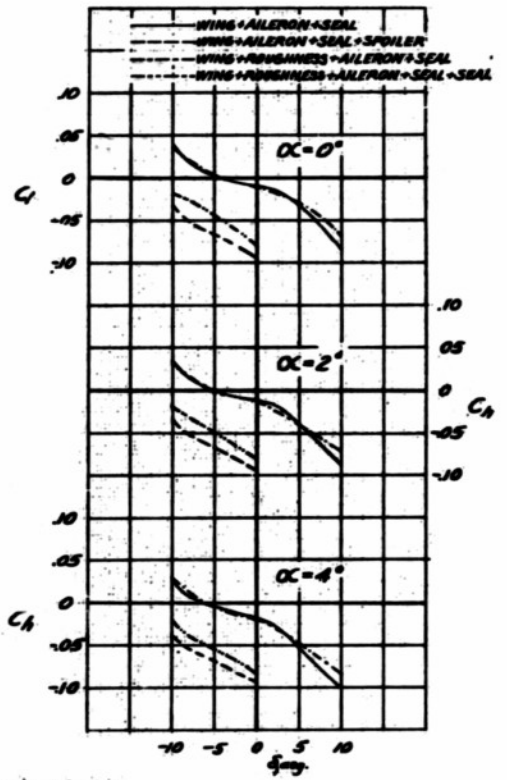
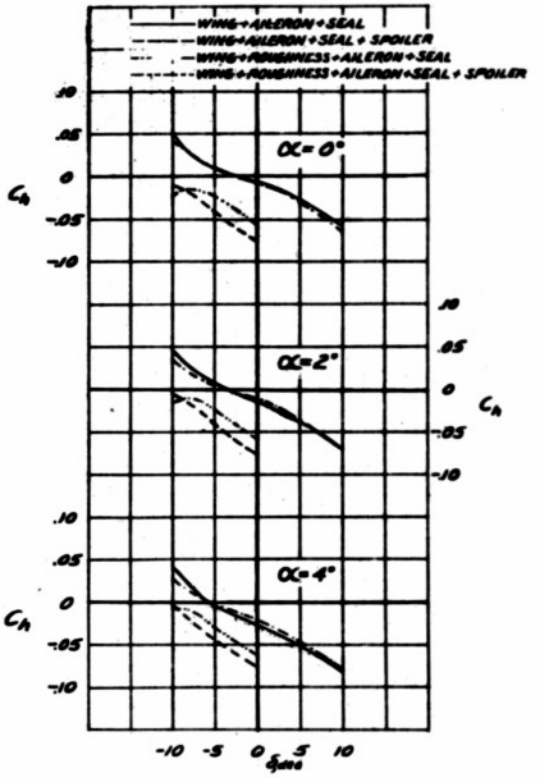


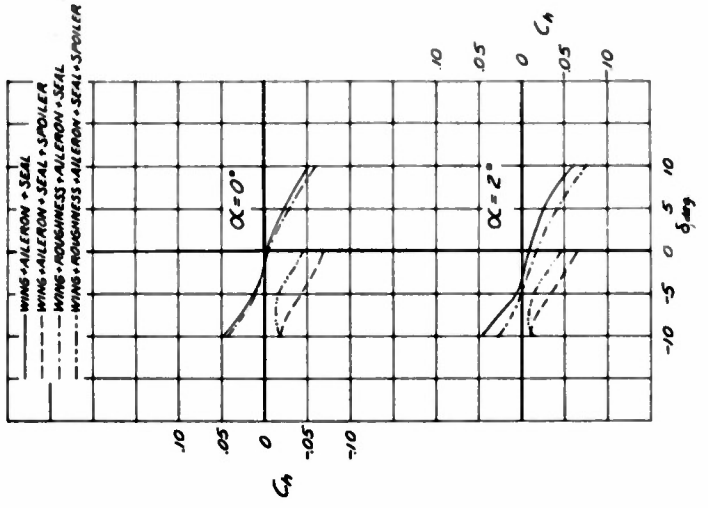
(a) - M = 0.3.

FIGURE 23 - EFFECT OF ROUGHNESS AT 0.02c ON AILERON HINGE-MOMENT COEFFICIENT FOR WING ALONE AND WING WITH SPOILER RETRACTED OF 0.02c ON UPPER SURFACE. AILERON SEALED. SPOILER AND AILERON TEST.



(a):- M = 0.6.

FIGURE 23 - CONTINUED. SPOILER AND AILERON TEST



(c)- M=0.2.
FIGURE 23- CONCLUDED. SPOILER AND AILERON TEST.

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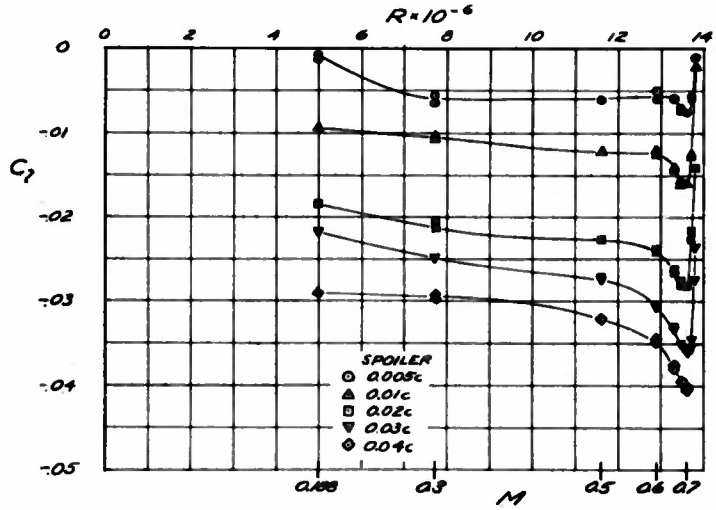

FIGURE 24:- VARIATION OF ROLLING-MOMENT COEFFICIENT WITH REYNOLDS NUMBER. SPOILERS ON UPPER SURFACE. $\alpha=0°$; $\delta=0°$. SPOILER AND AILERON TEST.

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8826

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AUTHOR(S): Laitone, E. V.; Summers, J. L.

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D.C.

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★ Spoilers

Aerodynamic control surfaces

Ailerons